LIFT IRRIGATION.

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INTRODUCTION.

THE articles reprinted in the following pages have been collected from a variety of sources and brought together in the hope that they may afford useful practical information to those interested in the development of the agricultural resources of this country. The longer articles were either originally contributed to the *Indian Review* or were published as Bulletins of the Agricultural Branch of the Department of Land Records and Agriculture. Most of the shorter articles first appeared in the columns of the *Madras Mail*, and to the Editor, Mr. H. K. Beauchamp, C.I.E., I am indebted for courteous permission to include the same. Between the various articles the only connecting link is that they all deal with various phases of the question of lift irrigation. These papers contain a fairly complete record of the experimental work done in Madras during the last ten years in connection with raising water for irrigation. One of them deals with irrigation by pumping in the United States, and nearly all of them contain proposals, many of which have recently been carried into practical operation with a fair amount of success.

During the last two years about 40 oil engines and

centrifugal pumps have been installed in this Presidency for irrigation work and the number is now very rapidly increasing. The earlier installations gave some trouble, but with increased experience that can now be avoided, and all the installations in private hands have yielded such satisfactory financial results, that their number is steadily increasing and there is every prospect that, in a year or two, there will be a considerable boom in this direction. It is very difficult to get accurate records of work done and results achieved where the engines and pumps belong to private owners, and one has to be content with the general terms in which they express their satisfaction and the readiness with which they are prepared to incur further outlay when such expenditure is obviously desirable. Two very important conclusions have been arrived at—

(1) That even with very small oil engines and pumps the cost of lifting water is less than one-half the cost of lifting water by means of cattle.

(2) That in the selected instances dealt with the provision of more powerful pumping appliances has been followed by deepening the wells or in other ways improving the source of supply, with the result that the available quantity of water has been very largely increased.

Previous to the installation of an oil engine and pump at Melrosapuram it is doubtful if there were any

wells in this country worked with more than six kavalais or mhotes, and on this assumption it would be safe to say that there was no well yielding more than 120,000 gallons of water a day for irrigation, but now under oil engines and pumps we have a considerable number of wells yielding this quantity of water and large tracts of country have been discovered where, with but little difficulty, wells yielding from 10,000 to 30,000 gallons of water per hour can be sunk.

Although great improvements can be effected by the adoption of oil engines and pumps in lift irrigation, it must not be forgotten that when everything has been done in this direction that can be done, still the great bulk of the irrigation under wells in this Presidency will either remain as it is or have to be undertaken by some mechanical method which can deal with much smaller quantities of water than is feasible with centrifugal pumps. Except in regard to capital outlay the windmill with a wheel from 12 to 16 feet in diameter forms an almost ideal motor for use on the wells which are to be found in the greater part of this Presidency. In most places there is sufficient wind and the wind blows with sufficient certainty to be relied upon for irrigation without having to provide inconveniently large storage reservoirs. It is not likely that much can be done to improve the wind engine, but our experience with pumps leads to the conclusion that the ideal irrigation pump has yet to be designed. The

time has not yet arrived when it will be safe to advise the wholesale introduction of windmills among the ryots, but the fact that they can be obtained with a capacity for lifting water equal to that of one, two or three mhotes, renders them extremely suited to the wells of this country, and there is but little doubt that over considerable areas where the wind movements are sufficiently strong, windmills will ultimately be as common in India as they now are in the Western States of America. It is, therefore, eminently desirable that experiments with windmills should be continued and that the failure of first attempts should not discourage further efforts.

Next to the mhote the piccotah worked by men is the most important machine for lifting water in use in this country. Where the sub-soil water is but a few feet below the surface it is almost universally employed, but it is not worked with advantage when the lift exceeds from 12 to 16 feet. Piccotah irrigation is very extensively pursued in most of the coast districts and generally in places where it is perfectly practicable to sink any number of wells capable of yielding sufficient water for the employment of centrifugal pumps. It is quite certain that, at the present time, piccotah irrigation is limited, not by the amount of water available, but by the supply of labour to work the piccotah. This is probably also true, to some extent, of mhote irrigation which is limited by the number of cattle

which can be conveniently spared for such work. The gradual expansion of water-lifting by mechanical means, whether it be by the oil engine and centrifugal pump, by the windmill and reciprocating pump, or by various water-lifting devices driven by electrically distributed power, is, therefore, to be welcomed as a material contribution to the development of the agricultural resources of the country, since there is no doubt that they will help to increase the supplies of water available for irrigation. Incidentally—and yet this by itself is a matter of great importance—the gradual extension of the employment of mechanical contrivances will greatly increase the efficiency of labour in this country. Already rice-hulling is, to some extent, done by modern machinery and of late a number of sugarcane-crushing mills have been installed of such a size as to necessitate the employment of oil engines to drive them. The results which have been obtained with these show a great saving in the cost of cane crushing and a considerable increase in the percentage of juice extracted as compared with the small iron mills driven by country bullocks.

The improvement of Indian agriculture is on all sides recognised as a matter of vital importance and there is a tendency among our agricultural experts out here to dwell too much upon the results which are likely to follow by the establishment of agricultural schools and experimental farms. The lack of capital

on the part of the agriculturist is the greatest obstacle that at present exists to the improvement of Indian agriculture, and when that capital is forthcoming the bulk of it can be spent to the best advantage by the agricultural engineer. The Government of Madras, by the application of the Agricultural Improvement Loans Act, has rendered it possible for wealthy ryots to obtain capital to develop their land at moderate rates of interest, but the working of the Act is somewhat cumbrous and its provisions regarding the security which has to be furnished for loans often render it impossible for ryots to avail themselves of it. In many cases the profits which can be realised from the application of water to land are so great that it is desirable that some convenient scheme should be devised whereby ryots should be able to obtain the advantages of water-lifting machinery more readily than they can do so at present. Frequently the minute sub-division of the land and the impossibility of getting landowners to co-operate presents almost insuperable difficulties, but in not a few cases if the machinery were supplied on the hire-purchase system it would prove a satisfactory solution. Messrs. Massey and Co., of the Napier Iron Works, Madras, have devoted a considerable amount of time to the working out of the details of such a scheme and they are prepared to supply oil engines and pumps for irrigation on payment of only one-third of the total cost at the time of the erection of the

machinery and the balance to be paid at intervals from the profits accruing from the irrigation. Before supplying machinery on these terms, the scheme is investigated by the Experimental Pumping Department and only accepted by the firm after it has been approved of by the department. Usually the hire-purchase system is a pernicious device for encouraging people to live beyond their means, but where the outlay is on machinery capable of yielding a large profit from its working, the system may be of great benefit to the agriculturist who has valuable land which is undeveloped for want of capital. A subsidiary advantage of the hire-purchase system is that, till the payments are complete, the machinery remains the property of the vendors and they are keenly interested in seeing that it is kept in thoroughly good working order. Where so great timidity still exists in regard to the employment of machinery, this is no small advantage.

DEVELOPMENT OF LIFT IRRIGATION. *

IN the Report of the Indian Irrigation Commission, it is stated that the total area throughout the country dependent upon wells for irrigation is nct less than 16 million acres, and the Commissioners, after discussing the prospects of utilising a larger proportion of the subterranean water, remark "that it may not be sanguine to look forward to a period when the area under well irrigation throughout India will have doubled." An exhaustive survey of the possibilities of extending irrigation by the construction of new works on a large scale led them to propose a programme for expending 44 crores of rupees in 20 years from which they anticipated an additional 6½ million acres of irrigation. That is to say, the Commission are of opinion that in the future, well irrigation will be of greater importance than it has been in the past, and of the land in India yet to receive the benefit of irrigation, not less than 70 per cent. will have to derive its supply from wells. At the present time only about 30 per cent. of the irrigation is under wells, but if the anticipations of the Irrigation Commissioners are realised, eventually the proportion will be much greater and may ultimately amount to as much as 45 per cent.

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Obviously, therefore, every possible aspect of well irrigation is a subject needing careful study and investigation and not the less so, because in the past it has not been deemed worthy of the serious attention of engineers. In various ways in different Provinces of India well irrigation has been encouraged by Local Governments, and to some extent material assistance has been rendered under the Agricultural Loans Act by the system of "Takkavi" advances, but nothing has been done to help the agriculturist in selecting the site for a well, nothing to show him how best to tap such water supply as may exist, and very little, and that of no practical utility, to indicate the best means by which the water may be raised above the surface of the ground. What has been done in the past has been done by the ryot himself, what yet remains to be done must necessarily be on much the same lines. But it is possible that valuable assistance may be given him in various ways and the range of his operations greatly extended.

In other countries notably in the arid regions of the United States, an enormous amount of work has been done to bring to the surface water for the irrigation of land, which would otherwise remain a sterile waste. Mainly the work has been done by private effort, but in America its importance is now being recognised by the State and the Federal Department of Agriculture devote a large amount of time to the collection of data and the publication of the results of experiments. Bulletin No. 158 of the Office of Experiment Stations is a record of Irrigation and Drainage Investigations carried out in 1904. No

inconsiderable portion of the 743 pages of this report deals with subterranean water and its utilisation, whilst the extensive development of pumping from rivers, lakes and backwaters receives the attention which it deserves. To Indian readers the record is interesting as showing what can be accomplished by intelligent enterprise and abundant capital. But the conditions in the Far West are so different from those that prevail here, that very little can be gleaned that is directly applicable to the circumstances with which we have to deal. Here as in America we must start *de novo* and work out the problems which will present themselves.

Under the Madras Government irrigation by pumping has received more attention than probably in any other part of India, and the history of work in this direction goes back as far as 1892. In his interesting report on the Divi Pumping Project which is now being carried out in the Kistna District at a cost of more than 18 lakhs of rupees whereby 50,000 acres of land will be irrigated by pumping from the Kistna river below the anicut, Mr. R. N. H. Reid, the Executive Engineer who designed the installation, remarks :

> The favourable financial position of the project naturally raises the question of whether the like cannot be done elsewhere, but before considering this, a brief retrospect may be taken of what has been done in the District since Messrs. Ussher and Chatterton first suggested the use of pumps for irrigation in 1892. In that year an area of 125 acres of land at Mattagunta in the Gudivada Taluk was irrigated by lifting water from the right bank of the Upputeru river which constitutes the outlet for the Colair lake. The average lift was under 5 feet, and a 4 horse-power portable

engine was used to drive an 8-inch centrifugal pump. In the following year, 1893, a second engine of 8 horse-power, driving two 8-inch centrifugal pumps was added to the plant of the previous year and an area of 820 acres was successfully cultivated. It was then decided to bring these lands at Mattagunta under anicut distribution by constructing the Pedalanka channel and the pumping experiments were accordingly discontinued.

Native enterprise then came forward and a firm of Guntur and Bezwada merchants were granted a concession enabling them to cultivate by means of pumping machinery an area of 1,000 acres on the margin of Colair lake for which they were to pay no water-tax. In the years 1894 to 1897, in spite of many difficulties from alternate flood and drought, they successfully cultivated several hundred acres. A want of expert advice hampered their efforts. The centrifugal pump employed which had a discharge pipe 15 inches in diameter, was too large to be economically driven by the small 10 horsepower engine, and the irrigation channels were far too large. A second native firm which came from Ellore started pumping in July of last year (1900) and successfully cultivated about 200 acres of land on one of the Colair lankas. They imported from Glasgow a 9-inch pump driven by a direct-acting vertical engine.

The successful pumping at Mattagunta naturally led to the suggestion of Divi Island as a suitable field for pumping on a large scale. Here was an area many times larger than any available on the margin of the Upputeru river and which, moreover, was quite cut off from the surrounding delta. I was in charge of Divi Island at the time as Sub-division Officer and in 1894 submitted a report with outlined estimate for irrigating 50,000 acres at a cost of about 14 lakhs of rupees in machinery and works. In 1896 a small establishment was sanctioned for taking levels and an alternative estimate was submitted for irrigating 30,000 acres of waste land, leaving the existing wet cultivation to be supplied from tanks as before.

Sanction was accorded in G. O. No. 1081—I., dated 22nd December, 1900, for the installation of a small pumping plant at Yetimoga which is 10 miles from the sea. Two twelve horse-power portable engines were brought to site and employed to drive three centrifugal pumps of 7, 8 and 10 inches diameter, the whole being housed under a galvanised iron-shed. Water was pumped from the latter end of June, 1901, into the village tank from which the ryots had been in the habit of cultivating from 50 to 100 acres whenever the river freshes were favourable. An area of 830 acres now is under cultivation. With the low water-tax of Rs. 3 for the year 1901, it was found that the net revenue paid 4 per cent. on the capital outlay. With the rate raised to Rs. 5 as in 1902 the return should be much higher. The plant now at site can irrigate 1,500 acres against the 830 acres of 1901.

The ryots at first viewed the experiment with their customary diffidence. No preparations for cultivation were made till the water was seen flowing from the pumps. It so happened that the season was very unfavourable for the old system of tank irrigation. In Yetimoga, instead of 830 acres not more than 50 would have been cultivated. The whole island suffered from drought, and in place of from 5,000 to 10,000 acres of wet cultivation under all the tanks the actual area brought to maturity was only a few hundreds. The area under the pumps at Yetimoga exceeded the total of all the rest of the Islands put together, with the result that the ryots of all the other villages are now petitioning for the extension of a similar system to their lands.

The Island of Divi, which is to be the scene of the largest development of lift irrigation which has hitherto been attempted, is situated at the mouth of the Kistna river, being cut off from the mainland on the one side by the main river and on the other by the Puligadda branch. It was originally intended to build an aqueduct across

this branch to carry the waters of the Kistna canals on to the island. But as the water supply available is barely sufficient for the lands already commanded by the Kistna canals, this project has been definitely abandoned and it is now intended to pump water from the bed of the river on to the island. The works, in course of construction, provide for lifting 500 c. ft. per second to a height of 12 feet and the plant will consist of 8 Diesel Oil Engines, of 160 horse-power each, driving 39in. centrifugal pumps. The water in the river is tidal and is only fresh during the irrigation season which begins in June and ends in December, so that the irrigation will have to be confined to paddy cultivation. The annual working expenses are estimated to amount to not more than Rs. 2 per acre and as the water rate charged will be Rs. 5, it is obvious that the project will prove highly remunerative. Apart from the shortness of the season during which water can be pumped from the river, the conditions at Divi Island are unusually favourable for a pumping scheme; especially is this so in regard to the variations in water-level, as the vertical range between the low spring tides when the upland water has ceased to flow and the maximum flood level is unusually small. In high floods no pumping is necessary and the greatest lift at the end of the irrigation season is not expected to exceed 12 feet. The small range of the tide at the mouth of the Kistna is largely responsible for the very favourable conditions of which advantage is now being taken.

The volume of water passing down many Indian rivers and now flowing uselessly to the sea is not only

enormously great, but the flow continues for a sufficiently long time to render it practicable to make use of the water for irrigation if only it could be obtained at a sufficiently high level to command lands suitable for irrigation. The Divi Island scheme may possibly be the forerunner of not a few similar installations, but much greater difficulties will have to be faced and the financial prospects are at the present time by no means so satisfactory.

Outside the deltas the rivers run in valleys and not only is the range between summer water-level and maximum flood-level very considerable, but the height to which water has to be lifted to command the land is generally so great as to preclude the possibility of pumping on anything but a very large scale. Nevertheless, it is certain that if the hydraulic conditions of the rivers in India are carefully studied, it will be found that there is an enormous field for the development of lift irrigation. In the south of India from many rivers large quantities of water are drawn off every year by the ingenious system of Spring Channels and where conditions are favourable this system of irrigation is fairly satisfactory. But in most cases it is only possible to obtain a small percentage of the water available and that by an expenditure of labour inordinately great. If the labour had to be paid for at anything like current rates for cooly labour, the cost of irrigation by Spring Channels would be found prohibitive. But Spring Channel irrigation is possible because it utilises in the slack agricultural season of the year labour that would otherwise be unemployed.

At the present time we know very little about the invisible flow of water down the river-beds during the dry season of the year. There is some evidence to show that it is fairly considerable, and that it might become a very important factor in the extension of irrigation if only it were properly looked after. It is certainly worth while to consider the question at some length. In the hot weather a typical Indian river presents a vast expanse of dry sand. A few inches or a few feet below the surface of the sand water is invariably found and in general the hydraulic gradient of the water closely approximates to the surface slope of the river-bed. By digging channels in the sand with the bed slope much less than that of the river, the upper end of the channel will have its bed considerably below the line of saturation of the sand, and water from the river-bed consequently flows into the channel. Proceeding downstream the channel gradually gets shallower and finally its bed coincides with the bed of the river. Before this point is reached, there is a point at which the water-level in the channel coincides with the water-level in the sand. Above that point water flows from the river-bed to the channel; below that point the water collected in the channel begins to flow back into the river and the sooner, therefore, the channel can be got out of the river and the bed made impermeable to water, the greater the quantity of water that will be available for useful work. If a Spring Channel with a slope of 2 feet per mile is carried up a river, the bed slope of which is 6 feet per mile, at the end of 2 miles its bed will be 8 feet below the bed of the river and if the

line of saturation is 4 feet below the river-bed, there will be, say, two feet of water in the channel at its head. Half a mile lower down the water in the channel will coincide with the level of the water in the sands; from this point onwards the channel will begin to lose water into the sand and the volume will gradually diminish till it is diverted from the river-bed into the more or less impermeable material of the banks. Obviously, therefore, a Spring Channel only taps the superficial layers of water-bearing sand and most of the water is allowed to flow by without being utilised.

A succession of Spring Channels, one below the other, is what is usually found in a river of this type and each succeeding one makes use of some of the water which passes by the upper ones. Beyond the head of the lowest channel all the water is wasted and in many cases this is undoubtedly a very large quantity, but how much it is extremely difficult to say. In addition, there is probably a very large loss of water by evaporation from the vast expanse of sand, but what this may amount to, there are absolutely no data by which to frame an estimate, though it would not be difficult to devise some simple experiments which would give practical information on this point.

From the foregoing sketch it will be seen that the extreme simplicity of a spring channel by no means compensates for its very obvious defects and it seems most probable that a well-devised system of lifting water from a river-bed by means of pumps would be more economical and would enable us to obtain a considerably

larger quantity of water. Spring Channel irrigation is only possible with *Kudimaramat* labour, of which it is difficult to express the money value. A low rate will put the cost of such irrigation at 2 annas per acre per day or, say, Rs. 3 per acre per month. This is, in itself, a fairly high charge but the real defect is the small proportion of water utilised of that which is available. In rivers with a fairly rapid bedfall and no great depth of sand the Spring Channel is most satisfactory, but when the bed slope is small and the depth of sand great, the Spring Channel cannot get at more than the water in the superficial layers of sand.

It is easy to point out in a general kind of way the advantages of lift irrigation from rivers, but when we come to the working out of details very serious difficulties present themselves, and as yet no attempt has been made to solve them. The water supply of certain towns like Conjeevaram, Trichinopoly and Madura depends upon the flow in the sand beneath the river-beds of the Palar, Cauvery and Vaigai rivers respectively. The expense to which a town may go to obtain a pure water supply is very much greater than what is permissible when the water is required for irrigation and the experience of the Sanitary Engineer who constructed these water supply schemes is, therefore, of little value to us in this matter.

Mr. Tota R. V. Ramanujam Chettiar, a wealthy sowcar, of Trichinopoly, has the honour of being the first native to grasp the possibilities which may be realised by pumping water to supplement the deficiencies of spring channel irrigation. He and his partners own a tract of

300 acres of land on the right bank of the Cauvery, a few miles below the junction of the Amaravathi with the main stream. These lands are watered by a spring channel which takes off from the Amaravathi some distance above its junction. The supply of water is always precarious and in recent years has often failed, so that the return from the land is very small. With the assistance of a loan of Rs. 8,000 from Government which has been granted to him under the Agricultural Loans Act, Mr. Tota Ramanujam Chettiar has erected a pumping station on the banks of the Cauvery in the immediate vicinity of the land to be irrigated. The pumping station has been erected on the high-berm within the river floodbanks and the engine house is placed at such a level as to be above even extraordinary floods. Two wells, one 15 feet and the other 20 feet in diameter, have been sunk in the sand about ten feet below the normal hot weather water level and connected together. In the smaller well two centrifugal pumps one with a suction pipe 12in. in diameter and the other with a suction pipe 8in. in diameter have been fixed and for driving them a 25 horse-power Hornsby liquid fuel engine has been installed. This engine is capable of driving one pump at a time but not both together. When the water level is fairly high the 12in. pump can be conveniently run, but if the water level sinks very low, there is only sufficient power to drive the 8in. pump. Between the engine and the pumps is a countershaft fitted with pulleys which renders this alternative arrangement possible. The two wells do not supply sufficient water to keep the 12in. pump at work and for the

present a channel has been dug through the high-berm into the lower bed of the Cauvery to a sufficient depth to bring to the pumps enough water to keep them going. This channel differs, however, very materially from the ordinary spring channel as its bedfall is practically the same as that of the river and it terminates suddenly with its water level below that of the water in the adjoining sand, so that it is simply an open filtration gallery.

This installation has been at work for one season now with great success. There has been trouble with the engine owing to certain defects in the arrangements for driving the pumps, but the land has been thoroughly irrigated and bears valuable crops of plantains and sugarcane whilst the neighbouring lands, which entirely depend upon the spring channel, have borne anything but satisfactory crops. During the latter half of the year the spring channel is the principal source of supply and it is when the water from that source fails that the engine and pump are set working. From the experience of a single year it would be very unfair to estimate the financial results which are likely to be obtained, but there is no doubt whatever that even in the first year the transaction has proved highly profitable and in years to come when the whole of the land has been brought under intense cultivation, the results will be still more satisfactory. This pumping station has been carefully watched by a number of other landholders, and there is not much doubt that there will be many more applications for assistance to put up similar pumping stations in other places. The maximum lift in this instance is not more than 16 feet and the

pump does nothing more than raise the water which is collected by a sort of infiltration gallery. The larger pump raises about 7 c. ft. per second and the withdrawal of such a small quantity of water has no appreciable effect on the Cauvery river. Even if twenty such installations were put up, the effect would probably be slight, provided they were not in too close proximity to one another. If, in course of time, it came about that there were as many as a hundred such pumping installations extracting from the bed of the Cauvery river a thousand c. ft. per second after all visible flow had ceased, it is probable that the pumps would have to draw the water from a much greater depth than at present. But, so far as I am able to form an opinion, I do not think they would have any difficulty whatever in getting the requisite supply of water as the bed of the river is a vast reservoir probably capable of yielding with suitable arrangements a much larger volume of water than 1,000 c. ft. per second.

This year a similar experiment will be made on the banks of the Hagari river, at the experimental farm which is being established by Government to deal with the question of irrigating black cotton soil. The pumping plant is now in course of erection and it will probably commence work at the beginning of June. A 28 H. P. oil engine and a 10in. pump have been purchased and the latter is to be erected over a well sunk at the edge of the bank of the river, and penetrating the water-bearing sand through its whole extent. There will be a certain amount of percolation into the well but it is not likely that it will be anything like sufficient to keep the pump

supplied with water. Arrangements to effect this have yet to be devised. Probably, in the first instance, an open cut will be made similar to that which has proved satisfactory with the Cauvery plant, but if the percolation into the well is free, a permanent infiltration gallery may probably be constructed of sufficient length to yield the quantity of water required. An essential part of the programme, however, is to pump as much of the silt carried by the water during floods as possible, and arrangements have been made to let the flood waters have free access to the pump.

The land to be irrigated by this installation runs back from the river for about a mile and the slope of the land in that distance is about 8 feet. This introduces, in a very mild form, one of the greatest difficulties which will have to be contended with in connection with introduction of pumping from rivers. In this case the difficulty will be got over by pumping in two stages. The water lifted from the Hagari river is carried back in a channel which runs in a bank about 4 feet high close to the pumping station and gradually diminishes in height till it becomes level with the ground and then runs in cutting up to the farm buildings where it is lifted into a channel running in bank by a second engine and pump. A similar plan has been adopted to deliver the water pumped from the bayous of Louisiana and Southern Texas on to the rice fields which, in recent years, have developed to such an enormous extent.

The variations in water level of the Hagari river are well within 20 feet, and as the suction of a centrifugal

pump will work well enough up to 25 feet, there has been no difficulty in placing the engine above any probable water level. But in most rivers the range of water level is much greater than this, and it is by no means a simple matter to arrange the machinery so that the engine is not submerged in high floods. Where the banks of the river are steep or almost vertical, the problem is a comparatively simple one as a well can be sunk in the river close to the bank and carried above the maximum flood-level. In the bottom of the well a horizontal centrifugal pump with a vertical spindle can be fixed and driven by a shaft carried up the well on which a horizontal pulley is fixed above the flood-level. The engine can then be fixed on the bank and drive the pump through a quarter-twist belt. The permanent masonry work connected with such a scheme must be fairly heavy and correspondingly expensive, and consequently the capital cost of an installation of this kind will amount to a good deal per acre unless the volume of water to be dealt with is large and the cost of the machinery is a considerable percentage of the total outlay. As yet no such installation has been erected in India and although pumping from the Nile in Egypt by means of steam engines and pumps has been practised on a very large scale, the prevailing conditions there are quite different to anything experienced in India except possibly in Sind with the Indus river.

In the case of most rivers the summer water-level is far below that of the surrounding country and the slope of the ground is not steep enough to allow of pumping the water in a single stage except by incurring the cost of very deep

cuttings, which would give an immense amount of trouble in flood time. Under such circumstances small pumping installations are out of thè question, as the capital outlay required will be too great. Where abundant water is available and there are large tracts of land to be irrigated it is probable that in most cases the engineering difficulties can be surmounted. It may be assumed that there is no objection to allowing the pumps to be drowned during the high floods but it is essential that the engines should be placed above the flood-level. The electric transmission of power would get over the difficulty provided the motors could be run back on rails whenever floods were expected. A large central generating station would be a very economical arrangement for pumping from a big river like the Godavari or the Kistna, especially if it were necessary to lift the water in two or more stages, and continuous pumping might be ensured even in flood time by the use of fairly long suction pipes and by making the stages overlap so that the suction pipes of the pumps on the second stage will begin to draw water from the main stream before the pumps on the first stage are drowned. In this case it will not be practicable to make the vertical stages more than 20 feet in height except the last one. Ordinarily, centrifugal or rotary pumps will be found the only types which it will be convenient to employ for irrigation work, but in some cases one or other of the various types of reciprocating pump may possibly be found suitable, the power being transmitted to it by wire ropes running on large grooved pulleys at a very high rate of speed. Where the lift is high and the slope of the ground gradual it will be necessary to

provide a rising main and in this connection it is possible that the employment of armoured concrete or armoured cement pipes may be found practicable and much cheaper than cast iron. All this, however, is more or less a matter of speculation and it is pretty certain that lift irrigation from rivers can only be gradually developed as one class of difficulty after another is practically surmounted.

On the Adyar river to the South of Madras, for irrigation purposes, two pumping installations have been erected. The first which was put up nearly two years ago supplies water to part of the land of the Agricultural College at Saidapet. Many years ago when these lands formed part of a garden belonging to the Nawabs of the Carnatic, a well was sunk near the river and connected thereto by a culvert. A few hundred yards lower down the river is a small masonry anicut which holds up a pool of water extending some distance beyond the Marmalong bridge on the Mount Road. On the side of the well, away from the river, a massive brick-work retaining wall was built which formed the end of an earthen bank thrown up to carry the water to the lands of the garden which are some 15 to 20 feet above the normal water-level in the river. Formerly a pair of country mhotes were employed to lift water from this well but two years ago we installed a $6\frac{1}{2}$ H. P. oil engine and a 4in. pump and on an average about 1,50,000 gallons of water per day have been lifted up for the irrigation of certain sections of the farm. The power available was hardly sufficient during the last hot weather when owing to the drought the river sunk to an abnormally low level.

A few miles further up the river at the village of Chittatur we have erected a 14 H. P. oil engine and a 5 in. pump for M. R. Ry. Appaswami Mudaliar. The river there consists of a series of rocky pools which have never been known to dry up and for a considerable part of the year there is a slight flow of water down from pool to pool owing to the leakage from the Chembarampakam tank and the drainage water from the lands under it. The banks of the river are fairly steep and the lift is about 23 feet. Some distance back from the hot weather channel, a well has been sunk and connected to the river by a culvert terminating in an open cut. In very high floods the pump will be submerged but the engine stands at a somewhat higher level and it is expected that the highest floods will not reach it. A moderately high bank carries the water from the pump to the level of the land, the lift being divided into about 16 feet of suction and 7 feet of delivery. The installation was only completed early this year at a cost of about Rs. 5,000 and it is hoped will provide sufficient water for 100 acres of land. So far the pumping seems to have had no appreciable effect upon the water-supply in the river, and if this be so, it may possibly be practicable to set up several other installations of the same kind.

It is well known that a considerable quantity of water passes down the Palar river in the wide sandy bed, and in an article published in this journal in August 1902 a scheme was outlined for sinking wells at intervals along side the river and pumping water from them with power supplied from a central electric station. The scheme was

submitted to Government in the Public Works Department and the proposal was so far approved that money was provided for establishing a single pumping station to test the practicability of getting at the water of the river by means of wells. In 1904 a site was selected near the village of Attur about three miles from Chingleput and a well 15 feet in diameter sunk at a spot which it was thought would prove satisfactory, and a sufficient area of land was acquired to test the practicability of irrigating by means of the water so raised. The well was sunk to a depth of 35 feet or nearly 20 feet below the water-level in the river but except for a few feet of blown sand on the surface and one or two thin layers of sand lower down it passes through practically impermeable strata. A boring was then put down from the bottom of the well for another 50 feet with unsatisfactory results. The well was found to yield about 20,000 gallons of water a day and was obviously a failure. I then had borings taken at various places on the land which has been acquired for experimental purposes and in some places more favourable indications were obtained. Finally a spot was selected about 250 yards from the existing well and a small pot well 2 feet 6in. in diameter sunk. This well only extends 5 or 6 feet below the level of the river-bed and its flow was recently tested with a hand-pump. Over 1,500 gallons of water per hour were taken out of the well and the depression of the water-surface was not more than 2 feet. This would mean that a 15 feet well with the same depression will probably yield 10,000 or 12,000 gallons per hour and by increasing the depression to 5 or 6 feet it is

probable that, without blowing up the bottom of the well, a supply of as much as 20,000 gallons of water per hour can be counted upon. The land acquired in the neighbourhood of the well has been converted into an experimental farm and placed under the charge of the Deputy Director of Agriculture. The anticipated supply of water will be more than sufficient for the irrigation.

The failure of the well at Attur and hundreds of similar failures which have occurred to ryots in well-sinking elsewhere, strongly point to the necessity of a preliminary exploration of the ground before incurring the expense of sinking large wells.

For this purpose well-boring tools capable of putting down holes about 3 inches in diameter are sufficient, and generally it is not necessary to go to a greater depth than about 50 feet. But over extensive tracts of country it will probably be found advantageous to put down boreholes of much larger diameter and to a much greater depth in the hope of tapping either artesian or sub-artesian supplies of water, or to penetrate beds of gravel from which water may be freely obtained by the use of deep well pumps. In Pondicherry and the country to the south of it, the existence of an artesian water supply has long been known, but it is not so well known that many hundreds of artesian wells have been put down by the ryots and that from these wells the water rises above the ground level and irrigates their fields. The quantity of water yielded by the wells varies very much, but in no case does it amount to more than about half a cubic foot per second. If pumping were resorted to, there is not the slightest doubt that

many of these wells could be made to yield a very large supply of water. Quite recently, Mr. Panduranga Mudaliar who, for nearly two years, has been irrigating his lands near Cuddalore with an oil engine and pump, has, with the aid of some men from Pondicherry put down a borehole at the bottom of his well. At a depth of 84 ft., he struck water and it rose up the borehole which was 7 inches in diameter with considerable force and filled the well to within 13 ft. of the surface of the ground. The engine and pump were set to work and about 300 gallons per minute were removed from the well. This resulted in lowering the water-level to about 20 ft. from the surface of the ground, but gradually the flow up the borehole decreased and eventually the well was emptied. With the borehole terminating at 28 ft. below ground level, a permanent discharge of about 140 gallons per minute was obtained. Subsequently, a second borehole of similar diameter was put down with a similar result, and Mr. Panduranga Mudaliar is now able to keep his engine and pump at work as long as he likes lifting over 300 gallons per minute from a depth of about 18 ft.

This discovery of a sub-artesian water-supply, as far south as Cuddalore, is of great importance as indicating that the beds from which the supply is derived are of considerable extent and probably of great capacity. Doubtless, numerous other boreholes will now be put down and eventually the demand for water will be so great that the natural flow of the wells will cease, and pumping will have to be resorted to everywhere to obtain a supply of water This is what has happened over and over again in America

and though enterprise and capital are not so freely forthcoming in this country yet, when the value of a perennial supply of water is fully realised, there can be but little doubt that the same sort of thing will occur here. The Pondicherry well-borers are very expert at their work and under favourable conditions put down boreholes to depths of as much as 300 ft. very cheaply and very expeditiously. Their skill and experience might well be utilised in many other parts of the Presidency, and if such work were systemmatically carried out, under competent supervision, whatever the direct results might be, there is no question but that the indirect results would be of immense value and would enable us to avail ourselves to the uttermost of such stores of subterranean water as actually exist.

Mineral explorations in the agency tracts of the Godaveri District have resulted in the discovery of fairly considerable supplies of artesian water and in the Chingleput District near Tiruvellore, Messrs. Best and Co., whilst boring for coal, have struck a fairly strong supply of artesian water at a great depth below the surface. In the neighbourhood of Cocanada and Samalcotah just to the north of the Godaveri Delta, artesian water has been found and a number of boreholes put down. But so far no attempt has been made to increase the flow of these boreholes by means of pumping. In Coimbatore where the water supply for irrigation is derived from many thousands of wells, the sinking of boreholes at the bottom of the wells has frequently led to tapping supplies of water under sufficient pressure to rise considerably above

the bottom of the well. Generally speaking, boring for water in the south of India has not been carried on very extensively, but the results of such work as has been done are of so encouraging a nature that further development in this direction is extremely desirable, and in course of time, it is not unreasonable to hope that the whole of the country will be carefully explored wherever the geological conditions are such as not to obviously preclude the possibility of finding artesian water in considerable volume.

In the Madras Presidency the general slope of the country is from West to East but the ridges forming the water-sheds between each river basin gradually become less prominent as they approach the alluvial tracts along the East Coast, so that variations in level of but a few feet would change the course of not a few of the rivers. In many places there are considerable tracts of water-bearing sand overlaid with alluvial deposits marking the ancient courses of rivers which may now be found working their way to the sea some distance off. Such beds of sand are invariably full of water, and in not a few cases where the lie of the land permits of it, the water can be brought to the surface by what is locally known as a 'springhead'. This consists of a channel dug at right angles to the contour lines with a very small slope so that eventually it pierces the layer of water-bearing sand and the water escaping by this artificial spring is conducted away for the irrigation of the lower lands. In practice this method of getting at the subterranean water involves a considerable amount of labour at the outset and only taps the surface of the water available. By sinking wells

into the sand and lifting the water out vertically much larger quantities can be obtained though naturally the cost of getting at the water is much greater. Our enquiries during the last twelve months have revealed the existence of very large areas of land from which such supplies of water can be obtained, and in certain places we have sunk wells with considerable success.

In the village of Pannampattu near Villupuram, we have installed a $9\frac{1}{2}$ H. P. engine and a 6 in. pump. The pump draws its water from a circular brick well which has been sunk on one side of a large open excavation. The water-bearing sands which rise within a few feet of the surface yield an ample supply and it is quite practicable to extract 1·50 cubic feet per second continuously from this one well. The soil round the well is extremely porous, otherwise such a supply of water would be sufficient for about 300 acres of garden crop. An effort is now being made under the direction of Messrs. Parry & Co., to ascertain what area of land can be irrigated and what crops should be grown to obtain the most profitable results. About 10 miles to the West of Villupuram, at Siruvanur, Mr. Pandurangam Mudaliar has sunk a well of the ordinary type employed in that locality. He has put in a 3 in. centrifugal pump and has been driving it for some time with an oil engine. The pump lifts about half a cubic foot per second and can be worked continuously day and night, the water-level in the well sinking very little. A similar well was sunk at Manamadura on the banks of the Vaigai river about two years ago and it has never been possible to unwater it with a 3 in. pump. Again at Pandur near

Trivellore in the Chingleput District several wells on the Lutheran Mission Settlements have been tested with a $3\frac{1}{2}$ H. P. engine and a 3 in. pump. In one case a sub-artesian supply was tapped and sufficient water obtained to keep the engine and pump fully at work and in other cases though the wells did not yield so much water, yet the quantity was sufficient to indicate that if a couple of wells were sunk and connected together, the percolation would be sufficient to keep the engine and pump running. At Pannampattu the sand yields water extremely freely but it also flows in easily so that it is difficult to separate the sand from the water and special arrangements will have to be devised to do this. At Siruvanur and Manamadura the sand is much coarser and no difficulty has been experienced in taking out the water.

In these tracts of land underlaid by water bearing sands where the lift does not exceed 16ft., the piccotah is universally employed and the area under well-cultivation is limited by the number of men available to work the piccotahs. This I have been assured is the case wherever I have made enquiries as to why when such a plentiful supply of water is available more use has not been made of it. Similarly, as in the country to the north of Trivellore where the water bearing sands lie at greater depth and the country mhote is used, the area under irrigation is limited by the number of cattle available for such work. The great majority of ryots are unfortunately far too poor and their holdings much too small to enable them to avail themselves of engines and pumps. If co-operation were possible something might be done, but it is almost hopeless

to expect anything in this direction and it is to be feared that many years will yet elapse before full use is made of the available stores of water which lie but a few feet below the surface of the ground over extensive areas in the Carnatic districts of this Presidency.

The vast majority of wells from which water is lifted for irrigation in this Presidency are little better than holes sunk in the shattered and disintegrated rock which occurs near the surface. In some of them a fair water supply is met with at a moderate depth. In other cases the holes are sunk to a great depth with less satisfactory results. As a rule, it does not pay to irrigate land when the water in the well is more than 40 or 45 ft. below the surface of the ground, but it is to be suspected that in many cases this is just about the level of the water plane in the dry season of the year. Where solid crystalline rocks are not encountered the deeper the well is sunk in disintegrated and shattered rocks, the greater is the water supply available and the greater the certainty that it will not fail. With modern pumping appliances it is possible to take out water very much more cheaply than is practicable with cattle, and there is not the slightest question that a very considerable percentage of the several hundred thousand wells sunk in the rocks of Southern India could be enormously improved if they were sunk still deeper and provided with adequate pumping machinery. Investigations in this direction are now in progress, and in certain cases where wells have been deepened, the supply has been materially increased. As instances of this I might mention the well at Melrosapuram and the well in the Jail compound at Coimbatore

where in both cases oil engines and pumps have been in use for several years. Other experiments in this direction are in progress, and though the time has not yet arrived when we can definitely ascertain the results, there is but little doubt of the correctness of the idea that the deeper we go the larger is the volume of water that can be obtained.

THE COST OF RAISING WATER.*

MORE than three years have now elapsed since we first started pumping water from a well at Melrosapuram with an oil engine; and is now possible to publish accurate figures as to the cost of raising water at that station. During the last 12 months a large number of oil engines have been set to work in this Presidency to lift water, but unfortunately under conditions which preclude the possibility of obtaining very reliable data regarding the cost at which the work is done. In most cases the actual expenditure incurred is, of course, ascertainable, but the measurements of the quantity of water lifted and the height through which it has been lifted have not been recorded. No case has come to my notice in which the owners of the engines are dissatisfied with the results obtained; and this is a matter of congratulation. From two or three typical stations, however, I have been able to collect data of sufficient value to show what has been accomplished and to indicate the direction in which improvements can be effected. The principal items which go to make up the cost of running an oil engine are :—

(1) The cost of the fuel used in the engine, which may be either kerosine oil or liquid fuel, and which has varied in price from 8 as. a gallon for the former and 2 as. a gallon for the latter.

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* *The Madras Mail*, 31st July, 1905.

(2) Charges on account of the capital outlay on the pumping station.

(3) The cost of labour employed in running the station.

(4) The cost of maintenance of the plant in good condition.

About each of these items a few remarks are necessary.

There are many forms of oil engine on the market at the present time, the great majority of which run very satisfactorily with kerosine oil; and since the expiry of the master patent of the Hornsby-Akroyd engine there have been several engines designed to work on the same principle as is employed in that engine. The principle involved in the working of this engine is the only one which allows the use of cheap fuel such as that available in Madras under the name of liquid fuel. It comes from Borneo and is the residual oil left after the distillation of the lighter oils. Till quite recently it has cost 3as. a gallon in Madras, but to stimulate its use in oil engines employed for pumping work the Madras Agents, Messrs. Best and Co., have reduced the price to 2as. per gallon, which enables us to effect a very important economy in the cost of pumping water. A gallon of liquid fuel weighs somewhat more than a gallon of kerosine oil, and roughly about the same amount of energy can be obtained from it; but it requires a slightly larger engine to develop the same amount of power. Experience seems to show that the brake horse-power obtainable by the use of liquid fuel in an engine is about 15 per cent. less than when kerosine oil is used. It is, therefore, necessary to employ a slightly larger engine, and this means a slightly increased capital outlay. At the present time, owing to the competition between the various oil supply Companies, kerosine oil is being sold at extremely

low rates and for Burmese oil we are now paying only 4 as. per gallon. But even at this rate it is hopelessly out of the running with liquid fuel at exactly half the price. Liquid fuel possesses the great advantage that it cannot be used in lamps and consequently presents little temptation to the engine drivers to steal it. This is really an important matter as there is absolutely no doubt that kerosine oil is purloined from pumping stations in very large quantities, with the result that the oil consumption of the engines is apparently very excessive. On the other hand, liquid fuel forms deposits inside the vaporiser which necessitates cleaning at frequent intervals. The cost of doing this is, however, very small; but as the work falls upon the driver he naturally objects to the use of liquid fuel, all the more so as it deprives him of the perquisite of a free supply of oil for domestic lamps.

The capital outlay on a pumping installation consists of two main items (1) the permanent masonry works and (2) the engine and pump. If the former are maintained in good order the deterioration is practically *nil*, but as regards the latter it is not an easy matter to determine what amount should be set aside annually to form a sinking fund to renew the machinery at the end of a given period. We have no experience as to what the working life of these pumping stations will be though with care and good treatment from 15 to 20 years would be a moderate estimate. It is difficult, however, to ensure that the engines are properly looked after and in the following calculations regarding the cost of pumping I have allowed 6 per cent. interest on the capital and have provided a sinking fund which invested at the same rate of interest will allow of the renewal

of the engines and pumps after $11\frac{1}{2}$ years. The annual charge on this basis comes to 12 per cent. If 4 per cent. interest on the capital be allowed and the sinking fund be invested at the same rate, a charge of 10 per cent. per annum will provide for the renewal of the engines and pumps in 13 years. If 5 per cent. interest be allowed then the 10 per cent. sinking fund provides for renewals at the end of $14\frac{1}{2}$ years, whilst a $12\frac{1}{2}$ per cent. charge would permit of the engines being renewed at the end of 10 years. It is, therefore, obvious that in determining the cost of pumping 10 per cent. per annum should be sufficient and that an allowance of $12\frac{1}{2}$ per cent. is more than ample.

If the engine be not run for more than 12 hours per day one man should be sufficient to look after it. The larger sized engines are provided with self-starters. The work of driving an oil engine is as light as it is possible to imagine. The engine will run for hours without any attention provided the lubricating arangements are in good order. My experience with native drivers, however, is most unsatisfactory. They learn to drive the engine without any difficulty, but it is impossible to teach them to refrain from tinkering at the engine; and when anything goes wrong instead of getting it put right in a common sense kind of way they adopt ingenious expedients of their own with deplorable results. A good many of the engines that have been in use for pumping water have suffered badly from the native drivers, mainly because these men are left entirely to themselves and the engines are not visited by any one competent to inspect them for months together.

Experience in this direction is slowly being purchased and time moderately reliable drivers will be available.

The cost of maintenance of oil engines in good condition should be very slight, but hitherto, it was unfortunately been extremely heavy owing entirely to ignorance, carelessness and want of experience on the part of the drivers. With an engine properly adjusted to the fuel it is using and kept in proper order renewals should be a very small item. About once in two years a new vaporiser will be required and from time to time the brasses, pump plunger and piston rings require renewal. At long intervals the valve seatings may want a little attention. And this is about all that should ever be the matter with the engine. The centrifugal pump is very simple machine and does not often get out of order provided it is properly lubricated. The belt, driving the pump, is probably the most expensive item in the way of maintenance and in my experience it requires renewal at least twice a year.

With these preliminary remarks it will now be possible to discuss the data which have been collected at Melrosapuram, the Agricultural College, Saidapet and at the Royapuram pumping station. At Melrosapuram the engine is a $3\frac{1}{2}$ h.p. Hornsby-Akroyd and the pump was a 3in. centrifugal pump by Gwynne & Co. In 1903-04 the pump was worked for 831 hours at a cost of Rs. 746 of which amount Rs. 300 is the charge on account of interest and depreciation, being $12\frac{1}{2}$ per cent. on a capital outlay of Rs. 2,400. The capital outlay is large for the size of the plant, but it must be remembered that this was the pioneer installation. The cost per hour amounts to 14·38 as. and for that sum

1,440 cubic ft. of water were lifted on an average 25 ft. At this rate 2,500 cubic ft. of water can be lifted 1 ft. for 1 anna. This is undoubtedly a very high rate, but it is mainly due to the very small number of hours during which the engine worked and the very large number of times that it has started and stopped. In all, the engine ran 334 times and the average duration of each run was in consequence only $2\frac{1}{2}$ hours, so that the amount of fuel used in starting the engine was out of all proportion to the amount of work done. From an irrigator's point of view the result is by no means so unsatisfactory, as the small number of hours during which it was necessary to pump water was due to the fact that the season as a whole was an extremely favourable one and the assistance of the pump was only required to a very moderate extent. In the following year the conditions were materially different. The rainfall throughout the year was slight, the North-East Monsoon was a complete failure and it was necessary to pump from the well all the water that could possibly be obtained. The engine was started 568 times and ran for 2,074 hrs. giving an average of 3·65 hrs. for each run. The working expenses, including interest and depreciation, amounted to Rs.1,088, equivalent to 8·39 as. per hour, and, as the work done was of similar character to that of the previous year, 4,290 cubic ft. of water were lifted 1 ft. for 1 anna. In 1903-04 the consumption of oil amounted to 786 gallons or 0·945 gallons per hour, which is nearly double what it ought to have been. In 1904-05, 1,691 gallons of oil were used and the average consumption was 0·815 gallons per

hour. During the first year the kerosine oil, which alone was used, cost 6·14 as. per gallon, but during the second year 728 gallons of liquid fuel costing 3·15 as. per gallon were mixed with 963 gallons of kerosine oil costing 6·7 as. per gallon. The total cost of oil during the year was Rs. 545-12-0. If liquid fuel at its present price had been used the cost of working would have been reduced by Rs. 323 and the running charge per hour to 5·9 as., so that 6,100 cubic ft. of water would have been lifted 1 ft. for 1 anna.

Saidapet Farm.—At the Agricultural College, Saidapet, a 6½ h. p. engine and a 4 in. pump were installed last year and I have before me the figures, supplied by the Principal, as to the running expenses of work done during the five months, from the beginning of November to the end of March. During that time the engine ran 712 hrs. and pumped 1,617,000 cubic ft. of water to an average height of 23·32 ft. The total working expenses including interest and depreciation at 12½ per cent. amounted to Rs. 476-12-0 and the average cost per running hour to 10·7as. From this data it is easy to calculate that 4,945 cubic ft. for 1 anna. It should be stated that during this period the engine and pump were not working very satisfactorily as the vaporiser was not properly adjusted to the fuel that was being used. At the beginning of April the engine was put into thoroughly good working order and the results for the three months April, May, and June are interesting. During that time the engine ran for 665 hrs. and pumped 1,333,000 cubic ft. of water to an average height of 27 ft. The working expenses amounted to

Rs. 317-10-6 and the cost per working hour to 7·65 as. at which rate 7,030 cubic ft. of water were raised 1 ft. for anna. If liquid fuel at 2 as. per gallon instead of Burmese oil at 4 as. 6 ps. per gallon had been used the running charges per hour would have been reduced to 6·14 as. and the amount of water lifted 1 ft. for 1 anna would have been 8,762 cubic ft.

Royapuram Pumping Station.—At this pumping station there are now several 40 h.p. Hornsby-Akroyd engines working on liquid fuel, and the data given below have been furnished me by Messrs. Massey and Co., and come therefore from an interested source. But I have checked all the details with great care and I have no reason to doubt their accuracy. In this case the engine ran 376·5 hrs. in thirty-three days and consumed 1,189·75 gallons of liquid fuel. The engine was working under full load and therefore developed about 32 B. H. P. The total running charges including interest and depreciation and maintenance amounted to Rs. 440 on the assumption that the liquid fuel cost 2 as. per gallon. It was not possible at Royapuram to measure the quantity of water or rather sewage which was lifted, but it is easy enough to calculate what amount of water could be raised by a suitable centrifugal pump when 32 h. p. were available for driving it. This calculation I have made with the result that I find that 32,770 cubic ft. of water were lifted 1 ft. for 1 anna. Roughly this is 3½ times as good a result as was obtained at Saidapet and is entirely due to the greater efficiency of a large installation as compared with a small one, to the much larger percentage of the running time to the whole

time involved, and lastly to the fact that the plant was running at its best.

These being the actual figures which have been obtained with oil engines and pumps it is obviously desirable that we should compare these results with those which can be obtained by native methods of lifting water. For this purpose comparison may be made with the single mhote. At the Saidapet Farm many years' experience with the working of such mhotes has resulted in the following estimate of the cost of lifting water. The average cost of a pair of cattle including a driver is taken as 12 as. per day and the cattle are supposed to work 8 hours, lifting 240 cubic ft. of water per hour to a height of 25 ft., which, expressed in the same terms as have been used in connection with oil engines, means that the cattle are able to lift 4,000 cubic ft. of water 1 ft. for 1 anna. About 10 years ago, as the result of a number of experiments on various forms of water lift I came to the conclusion that under the most favourable circumstances the ryot could lift 6,820 cubic ft. of water 1 ft. for 1 anna; but subsequent experience leads me to think that this estimate was framed on data extending over too short a period and that in actual practice it is utterly impossible to realise it. Recently in the neighbourhood of Trivellore I was able to get some data which I have reason to believe represent not unfairly what can be done at the present time in that locality. A pair of cattle working on a 20 ft. lift raised 30 buckets of 20 gallons per hour, or in 9 hours lifted 5,400 gallons of water to a height of 20 ft. The *mamool* rate for the hire of cattle, to work a mhote in that District is Re. 1 per

day, which, of course, allows a considerable margin of profit to the owner of the cattle. Assuming that the cost of the cattle, which were not very good ones and not in good condition, was only 8 as. per day, the result is that 2,160 cubic ft. were lifted 1 ft. for 1 anna. At the present time when water is so badly wanted for irrigation the cost of lifting it by native methods is at its highest. Cattle are usually fed on gram and straw, and the former is certainly 50 per cent. above the normal rates, whilst the latter is being sold at between 5 and 6 times the price in an ordinary season.

From the data which even now I am able to present regarding the cost of lifting water it will be seen that the final result has not yet been arrived at. There are so many factors which go to make up the total cost and these vary very much from time to time and from place to place so that anything more than rough and general statements are hardly possible. Under very favourable conditions it may be assumed that with cattle 4,000 cubic ft. of water can be lifted 1 ft. for 1 anna and with small oil engines I think there is sufficient evidence to show that under similarly favourable conditions at least double the amount of work can be done for the same money; but when the water supply is large and it is possible to install a big pumping plant the working expenses are very much less and amount to but from $\frac{1}{6}$ to $\frac{1}{8}$ of those which would be incurred if cattle were employed.

These questions are great interest at the present time when the rains have been holding off for so long a period and many wells have dried up entirely. During

the past few months I have been able to gather considerable evidence that at greater depths than the agriculturists of this country have hitherto sought for water there is a good deal yet to be obtained and if the cost of lifting it has been reduced by one-half it surely follows that where the supply is sufficient to make it worth while to install an engine and pump there it will be wise to set them up. In a normal year the ratio of working costs is only 2 to 1, but in a year like the present the ratio is much higher and if the Trivellore data may be accepted as fairly accurate, the ratio is practically 4 to 1. There is a generally prevalent idea that the wells have dried up to a large extent and this is certainly true in many Districts, but I am still of opinion that there are enormous quantities of underground water which may yet be easily obtained if only the trouble is taken to locate them. Only a few days ago I found abundance of water in the wells between Trivellore and the Kortelyar river at a depth of 20 ft. below the surface of the ground and in the country round Villupuram and away down to the coast at Cuddalore there is abundance of water at a depth of about 16 ft. Again, in the valley of the Vaigai in many places the water supply seems to be extremely abundant as is evidenced by a small well sunk near Manamadurai which is capable of supplying 40,000 cubic ft. a day or sufficient to water 13 acres of land to a depth of 1 in. I have mentioned these places which have come to my knowledge in the hope that those who are interested in the question of subterranean water supply will make careful observations in their own neighbourhood and send me

the results. It is seldom such an opportunity occurs and it would be a pity that it should be entirely neglected. Now is the best time to sink new wells, to deepen old ones and to gather reliable information regarding the stores of water which are available at moderate depths below the soil.

IRRIGATION BY PUMPING—I.*

THE problem of lifting water from one level to another presents many phases and under certain conditions calls for the highest engineering skill and mechanical ingenuity. The natives of India, as the result of the accumulated experience of centuries, have with the Persian wheel, the mhote, the piccotah and the basket scoop, reached a high degree of perfection in their methods of applying animal or human power to the raising of water for the irrigation of small patches of cultivation. Over and over again the defects of native appliances have led to attempts being made to improve them, and especially in recent years a very large number of patents have been taken out for water-lifts by all sorts of people. Some of these by dint of advertising have met with ephemeral success, but in no instance has a modern water-lift survived the test of time. The piccotah and the mhote, each in their own way, are better suited to the conditions under which the Indian ryot works than any of the more efficient but more complex machines for raising water which have been devised.

The experiments which the Government of Madras are now undertaking to test the feasibility of employing modern motors and pumps for irrigation on an extensive scale have attracted a great deal of interest throughout the

* *The Madras Mail, 1905.*

Presidency, as evinced by the correspondence which from time to time appears in most of the daily papers. A careful perusal of the letters which have been published shows that very little is known about the question and that most erroneous views prevail everywhere. It is therefore proposed in this and in future articles to state as far as possible in simple and non-technical language the facts regarding the possibilities of the various forms of motive power which can be employed in this country for the purpose of raising water.

The millions of wells scattered all over the country attest the enormous importance of well irrigation, but it is estimated that throughout the length and breadth of India not more than 1 per cent. of the total rainfall is recovered from the water stored beneath the soil. A survey of the wells of the Presidency reveals the fact that by far the great majority yield a supply of water less than or just sufficient to keep a single water-lift at work. That is to say, the capacity of the wells is determined by the capacity of the means employed in unwatering them at the time they were sunk. More powerful pumping appliances would have enabled a much greater depth to have been obtained, and it is unquestionable that the available quantity of water would in consequence have been enormously increased. It must, however, be fully recognised that the effect of pumping on a large scale will be to lower the level of saturation; and the amount of work which will have to be done to obtain a larger supply of water will be greater in proportion to the quantity obtained than at present. It, therefore, follows that if

improved methods of doing work are to be successful they must be not only more powerful but also very much cheaper.

From experiments which have been made in various places it appears that the cost of raising water by native methods is by no means so cheap as is generally supposed. Experience extending over many years at the Agricultural College, Saidapet, has enabled the authorities there to state that they are able to raise 4,000 c. ft. of water 1 foot high for 1 anna, which means roughly that the cost of irrigating an acre of land to a depth of 1 inch from a well 25 ft. deep is about Rs.1-8. This may be accepted as the cost of irrigation under favourable conditions in normal years. But in seasons like the present the cost of keeping cattle in good condition and fit for the heavy work of water-lifting is more than doubled, and it would be certainly within the mark to say that at the present time to lift an acre inch of water from wells 25ft. deep costs more than Rs. 3. It is, therefore, almost impossible to obtain accurate figures regarding the cost of native methods of lifting water. It is always a heavy item, but it is difficult to express it in currency terms. It varies materially from year to year, and unfortunately in dry years when water is most wanted, then the high price of fodder makes the cost of water-lifting extremely heavy.

Now, with mechanical appliances the conditions are much more favourable. The seasons do not affect the price of fuel, and though throughout the year interest charges have to be paid and a man must be kept to look after the engine, yet when the rainfall is favourable and little water

is required the cost of running and the depreciation are very small. On the other hand, in times of drought, when the quantity of water required is very large, it is easy to run the engine for longer hours to obtain a much larger supply, and the extra cost of doing this is usually more than compensated for by the enhanced prices which the products of agriculture then yield.

From the experiments which have been in progress throughout the last three years it has been possible to obtain fairly accurate figures regarding the cost of raising water with oil engines and pumps. But any attempt to compare these figures with those which would have been obtained had native appliances been used is almost impossible owing to the extreme difficulty in estimating what would have been the cost of doing work under such conditions. I shall certainly not overstate the case in favour of the oil engine and pump when I claim that they are capable of doing the work at less than one-half the cost of native methods; and this too when the scale of working is unfavourably small. Where the area to be irrigated is large and the supply of water abundant there is no comparison between the two methods. To lift 500 c. ft. a second to a height of 15 ft. with cattle power is outside the region of practical working; yet it presents no difficulty whatever to the engineer and, in a comparatively short time, those interested in the adoption of these new methods of raising water will be able to see an installation of this size at work in the Kistna District. The larger the units with which we can work, the greater the economy that can be effected. The difficulty with motors

and pumps is to get them to work cheaply when the volume of water available and the area to be irrigated are small.

The statistics of well irrigation in this Presidency show that the average area under a well is only $2\frac{1}{2}$ acres, and that therefore the quantity of water taken out probably does not amount to more than one hundredth of a cubic foot per second, or, say, 12 gallons per minute during the working hours of the day. Many wells are, of course, capable of yielding a much larger supply than this, but few have a capacity sufficient to give full employment to even the smallest size of engine and pump which it is considered advisable to install. It must not, however, be imagined that because such wells do not exist they could not be constructed if it was advantageous to do so. Enquiries, supplemented in some cases by experiments, during the last few months have placed beyond doubt the fact that wells yielding large volumes of water can be obtained over considerable areas of country. And perhaps what is still more important, it has been ascertained that there are large supplies of water available in many nullahs and streams which could be used for irrigation by the application of adequate pumping power. It would be unwise to attempt to estimate the extent to which in the future it is possible that engines might be used for pumping, but it seems clear that there is room for the profitable employment of a very large number of such installations.

IRRIGATION BY PUMPING—II.*

IN a report on waterlifts written in 1896, I said :—"Steam pumping machinery is utterly beyond the means of the ryot, and the force of the wind is too uncertain, and in general in India it is too weak to be profitably utilised by windmills, even of the most modern type. Animals are therefore the only source of power available, and waterlifts in future must continue to be, as they always have been, worked by cattle." In the main this is still true, but within less than a decade the advances which have been made in the generation of power by internal combustion engines have been so extraordinarily rapid that it is quite possible now to compete with cattle whenever the work to be done is as much as would require the services of three or four pairs of oxen. Expressed in engineering terms, the work done by an average pair of cattle may be taken as one-fifth of a horse power, which is equivalent to the lifting of 26·4 gallons per minute from a depth of 25 ft. At this rate half-an-acre of land will be covered to a depth of one inch in 7 hours; or, to put it in the language of the ryot, a pair of oxen can water half-an-acre of land a day, and as stated in the first article of this series, the cost of watering will amount to Rs.1-8-0 per acre.

* *The Madras Mail*, 1905.

Now a Hornsby-Akroyd oil engine, developing $3\frac{1}{2}$ h. p. and employed to drive a 3-inch centrifugal pump, will do as much work as 7 pairs of cattle, and it can easily be run for 12 hours a day, so that it may be taken as the equivalent of 10 pairs of cattle, and it will therefore water 5 acres of land a day, and the running expenses will not amount to more than Rs. 3-8-0, or, say, eleven annas per acre. So that where there is an adequate supply of water the cost of pumping is less than one-half that entailed by doing the work with cattle. When the supply of water is insufficient to keep such an engine and pump running for 12 hours a day, the cost of working will be greater; and when the pump can only run for four hours a day the cost of lifting water will be the same by either method. The average discharge of the pump may be taken as 11,000 gallons per hour; so that roughly the minimum supply of water which should be available, if an engine and pump is to be installed, is 45,000 gallons per day, or sufficient to give one watering to 2 acres of land. Of the more than half-a-million wells from which water is drawn for irrigation in this Presidency, comparatively few would be able all the year round to yield the minimum supply required; but even if the number were only one per cent. we could profitably employ something like 5,000 oil engines and pumps. Whether one per cent. of the wells are capable of yielding the supply of water or not, it is impossible to say, as there are no data to go upon; but it is almost certain that a very much larger percentage of wells than this could, at a comparatively small cost, be improved so as to yield a good deal more than the minimum quantity of water

required. All that is necessary is to deepen them and to pump out the water from a lower level, so that the gradient of the subsoil water flowing to the well may be increased.

The smallest sized centrifugal pump which we can conveniently employ for irrigation work is one having suction and delivery pipes of 3 inches diameter. Pumps of smaller size than this are made, but owing to their small diameter they have to be run at a very high speed, and the friction of the water, both in the pump and the piping, absorbs a very large proportion of the power, and their efficiency is extremely low. In general, the efficiency of centrifugal pumps increases with their size, provided that the lift be not too small.

A 3 in. pump will deliver 11,000 gallons of water per hour, and if the inflow to a well were equal to that amount, the daily yield of water should be more than a quarter of a million gallons, which is six times the minimum quantity required. An inflow of 2,000 gallons per hour is sufficient to make it worth while to install an engine and pump, but it will be necessary to provide sufficient storage capacity to enable the water to accumulate at the bottom of the well till it amounts to a sufficient volume to make it worth while to run the engine. This is what has been done at Melrosapuram, where, to start with, the we was 21 ft. in diameter and 21 ft. deep, with a central hole 15 ft. in diameter and 7 ft. deep, the latter capable of holding 7,700 gallons of water. Observations showed that the rate of percolation into the well decreased very rapidly if the water rose above the rim of the central hole. To pump out the central hole took about an hour,

and then the engine had to be stopped till it filled again. Both storage capacity and percolation area were materially increased by running adits horizontally from the bottom of the well. The total length of these adits was 68 ft. and their average width 2 ft. and, as they were about $5\frac{1}{2}$ ft. high, they held when full, 4,575 gallons of water. It was desirable, however, to increase the storage capacity considerably beyond this, and accordingly a new well 30 ft. in diameter was sunk a short distance from the original well and the two connected by prolonging one of the adits. The total area at the lowest level from which water is drawn is now 1,044 sq. ft., and with 5ft. depth in the well, the storage capacity is nearly 33,000 gallons, or sufficient to keep the engine running for three hours without taking into account the percolation during that time. The advantage of this large storage capacity has been fully realised during the last few months when, owing to the long drought, the rate of percolation into the well has fallen as low as 1,500 gallons per hour. By allowing this to accumulate it has been possible to extract, with fair economy, every drop of water that could possibly be obtained and to keep the cultivation going on about 12 acres of land. This very small quantity of water, supplemented by the local rainfall, has proved sufficient to keep the crops in fair condition, though it is probable that the outturn this year will not be as favourable as usual.

Where the height to which water has to be raised is small, engines of less than $3\frac{1}{2}$ h. p. may well be employed. A 2 h. p. engine will drive a 3in. centrifugal pump on a 12ft. lift, and this is about the smallest combination of

engine and pump which can be profitably employed. The advantages of a large storage capacity seem to have been fully realised by the ryots, and many of their wells have a much larger storage capacity than that which has been provided at Melrosapuram. In not a few cases, by going deeper a much larger volume of underground water will become available. The depth from which ryots draw water varies considerably in different parts of the country and is probably deepest in Coimbatore and the Ceded Districts, where it is not uncommon to lift water from a depth of 40 ft. So far, in Madras, centrifugal pumps have not yet been employed on lifts exceeding 40 ft., but at the Coimbatore Jail an oil engine is driving a pair of plunger pumps which lift the water 75 ft. As experience accumulates we shall probably find it profitable to go deeper and deeper and there is no reason why with centrifugal pumps we should not be able to profitably lift water to a height of as much as 100 ft.

Since these irrigation experiments were started, a very large number of possible sites for pumping stations have been investigated, and the greatest difficulty experienced in working out profitable schemes has not been the height to which it was necessary to lift water, but the expensive arrangements which were found necessary to cope with the enormous variations in the water-level at different seasons of the year. Fluctuations of 40 ft. or 50 ft. are not at all uncommon where the water supply is derived from river beds or nullahs; and even in wells the range may be not far short of this. With centrifugal pumps the maximum length of the suction is about 25 ft., and up to that limit

the variations in the water level give practically no trouble; but beyond that point the installations become very expensive, and as yet we have not ventured to tackle them.

The other chief difficulty which we have encountered in our investigations is the very gradual slope of the land between the place where water can be obtained and the place where it can be utilised. This entails the construction of high earthen banks to carry water over the low ground, or the employment of iron pipes in which the water can be carried under pressure. Both expedients are costly, and no satisfactory solution has yet been arrived at. Where large quantities can be dealt with, the difficulty may be got over by dividing the total lift into stages and employing two or more sets of engines and pumps, one at each stage. This plan has been adopted at the pumping station which is now under construction for the experimental farm on the Hagari River, in the Bellary District. In this case a 25 horse-power engine and 10 inch pump lift the water from the river a vertical height of about 16 ft.; and it is then carried about a mile from the river bank, the channel gradually getting into a deep cutting, till, at a convenient point, such water as is required for the irrigation of the high level land is lifted out by a second engine and pump. As a temporary arrangement a $3\frac{1}{2}$ horse power engine and a 4 inch pump will be installed; but later on, when cultivation has fully developed, a more powerful pumping plant will be supplied.

IRRIGATION BY PUMPING.—III.*

MAKERS of centrifugal pumps invariably state their capacity in gallons per hour; but in dealing with irrigation work the units are inconvenient, and it is preferable to employ a unit of volume rather than one of weight. Engineers in India have adopted the cubic foot per second abbreviated into "cusec," which is admirably adapted for dealing with the discharges of canals or channels to large systems of irrigation. In America, where the farmer's influence predominates in irrigation works, the acre-inch or acre-foot, that is to say the quantity of water which will cover an acre of land to a depth of an inch or a foot, is the unit most commonly employed. Now, a cusec is equal to 3,600 c. ft. per hour and an acre-inch is equal to 3,630 c. ft., so that for practical purposes a cusec flowing for one hour is equal to an acre-inch.

It has already been stated in a previous article that for irrigation work it is not convenient to employ anything smaller than a 3-inch centrifugal pump, and that such a size of pump is capable of delivering half a cusec, or sufficient water to cover an acre to a depth of one inch, in two hours. Our experiments have also led to the conclusion that unless a well can supply sufficient water to keep such a pump running for four hours a day it will not be worth

* *The Madras Mail*, 17th October, 1905.

while installing an oil engine to lift the water; that is to say, the minimum yield of a well must be two acre-inches or 7,260 c.ft. per day. This is equivalent to a continuous inflow during the 24 hours of slightly over 300 c.ft. per hour. On a lift of 21 ft. this would be about the quantity of water that would be raised with a mhote worked by an average pair of cattle. Those who are acquainted with well irrigation as it is at present practised will readily admit that there are a very large number of wells in this country which in ordinary years could not be unwatered by a single mhote.

The question therefore whether a well will yield sufficient water to make it pay to put down an engine and pump is not a difficult one to answer if observations are made on the well at the right time of the year, or better still if observations are made on the well two or three times during the year. Applications are very frequently made to me for the expression of an opinion as to the possibility of obtaining sufficient water from a well, and as the experiments to obtain data for framing an answer are extremely easy to carry out, I propose to detail at some length what should be done so that any intelligent person may be able to obtain an answer himself.

The rate of percolation into a well is mainly effected by the depth of water standing in the well. If no water is drawn from a well for several days, the level of water in the well will be the same as the level of the water in the surrounding strata, and a state of equilibrium will be established. Immediately water is removed from the well, the level sinks, the equilibrium is disturbed and water from

the surrounding strata begins to flow into the well. Obviously, the lower the water level in the well is depressed, the more rapid will be the inflow, and the maximum will be reached when the well is quite empty. In a Note on "Irrigation by Pumping from a Well at Melrosapuram," which will be shortly published as an Agricultural Bulletin by the Department of Land Records and Agriculture, I have given both in tabular form and diagrammatically the results of a considerable number of measurements of the inflow to the well at different times in the year; and those who are interested in the matter can easily obtain a copy of the pamphlet.

Quite recently I was asked by the Court of Wards whether certain wells on the estate of a Minor would yield enough water to make it worth while to put down an engine and pump. One of my assistants was sent down to make a survey of the place and to carry out experiments necessary to obtain some notion about the quantity of water which could be obtained from the wells. A brief account of what he did, the results he obtained, and the deductions which have been drawn from his observations will exemplify the way in which we endeavour to solve such problems.

He found that there were two wells about 250 yards apart, both approximately rectangular and sunk through decomposed rock. The northern well was 65 feet long and 35 feet broad, with a water surface of 2,200 sq. ft. It was possible to bale water out of the well with two mhotes, which were worked together and the combined capacity of which was found to be

8 c. ft. When baling was started the lift was 17·22 ft. and the cattle were able to lift 224 buckets in the course of the first hour. A gauge, reading to feet and decimals of a foot, was fixed in the well and arrangements were made to count the number of buckets lifted each hour and to record the level of the water at the time. Baling was carried on continuously for 41 hours, at the end of which time it was found that the cattle were not able to lower the water level in the well any further. Starting with 224 buckets per hour with a lift of 17·22 ft. the number decreased to 144 buckets per hour when the water was raised 24· 32 ft. It is impracticable here to publish a tabular statement of the results recorded, but I have had them plotted in diagrammatic form and I find that from the start till the water level was lowered to 24 ft. the inflow increased proportionately to the lowering of the water level, but that from this point onwards the rate of increase was enormously more rapid, being from 424 c. ft. per hour with a level of 24 ft. to 576 c. ft. per hour when the water level was lowered an additional 4 inches.

Beyond this the experiment unfortunately could not be carried as no further pumping power was available. There was still 3ft. of water in the well and the inflow would have probably gone on increasing if this could have been removed. I have therefore expressed the opinion that the well will yield sufficient water to justify the establishment of an engine and pump, though I am not prepared at the present time to say how much water can be counted upon. That is a matter which only the experience of two or three years' irrigation will enable us to decide. I have advised

that a 4 in. pump should be fitted up and driven by an engine of sufficient power to lift the water from a depth of 35 ft. below the present discharging level. This would enable the well to be deepened if necessary another 10 ft. and would undoubtedly enormously increase the flow into the well. The pump will lift about 3,000 c. ft. per hour and will be capable of dealing with the inflow to the well under existing conditions in about five hours a day. It is impossible to say how much larger an inflow will be obtained when the well is deepened, or whether it will continue for any length of time, as after the rains are over the subsoil water level gradually sinks, and in a corresponding way the inflow to the wells decreases. Where extensive pumping is carried on it seems obvious that these changes will take place more rapidly and that a very considerable volume of rock may be drained of water during the year by a deep well. In this case, if we assume that the well is deepened to 36 ft. and that the surrounding strata contain 10 per cent. of water, the pump, if worked for eight hours a day, will in the course of 200 days, which may be taken as the interval during which time the subsoil water receives no replenishment, drain an inverted cone of rock about 2,270 ft. in diameter at the ground level. At first the diameter of the cone will be small and the hydraulic gradient steep, so that percolation will be rapid, but as the water is drawn off from the rock the base of the cone will extend and the rate of inflow will diminish.

The southern well on this estate is very nearly square, the dimensions being 55 ft. by 52 ft. and the water surface

2,800 square feet. Baling was carried on for 51 hours, with the result that the water level was lowered and the lift was increased from 22·36 to 28·6 ft. when the water level remained constant under a draught of 465 c. ft. per hour. With a similar depression of the water level in the nothern well the inflow was only 360 c. ft. per hour, so that, if anything, this well is likely to yield more water than the northern well. It is probable, therefore, that a 4-inch pump might also be installed in this well with great advantage. After a time the pumping from one well will begin to affect the inflow to the other and the total quantity of water raised from the two wells will be considerably less than that which would be obtained from either one of them separately assuming that the other is not worked. In this case I have suggested that one engine only should be installed, which should be placed so as to drive the pump in one well in the ordinary way, and that it should drive the other pump 250 yards off by means of a wire rope running over pulleys of large diameter.

These two wells are of a type common enough in this country. If sunk to a sufficient depth they may safely be reckoned to yield a moderate supply of water for a fairly long time. In ordinary seasons the ryots draw from them but a small proportion of the water which might be obtained, but in dry seasons, like that we have just experienced the whole of the water supply is made use of. Many of these wells are very old and have passed through a number of abnormally dry seasons, so that they have reached the maximum depth that it pays to

sink them when the water has to be drawn from them by cattle power. As a rule, on examination they are generally found to contain a considerable quantity of silt, and the fact that this has been allowed to accumulate through a number of years seems to indicate that the ryots find that it does not now pay them so well as it formerly did to lift water from a great depth for well cultivation. This evidence is not very conclusive by itself, but it is borne out by the fact that all over the country wages, food and fodder are steadily rising in value and the cost of raising water is therefore increasing. The value of produce is also rising, but whether at an equal rate or not it is difficult to say. What seems to be more certain is the fact that the soil is becoming exhausted and that either poorer crops are raised or more money has to be spent on manure.

In the coast districts, wells are sunk through beds of alluvium till water-bearing sands are reached. The rate of percolation in such wells is usually very slow, on account of the compact nature of the sand, and as the wells have to be constructed by sinking cylinders of brick work they are seldom over 20 ft. in diameter. Consequently, they possess but little storage capacity and engines and pumps can be used only in a few of them. Where these water-bearing sands are within a moderate distance of the surface the best way of getting a large supply of water from them is to make an open excavation, and at the bottom of it sink a number of wells in a line, connecting the wells one with the other by iron pipes, which can be worked through from well to well if the intervening space be not too great. The wells from which Mr. Pandu-

ranga Moodelliar is pumping water near Cuddalore belong to this type. He started with one well 12 ft. in diameter and has sunk alongside it a second well 20 ft. in diameter, and now he proposes to sink a third well so as to obtain an increased area of percolation and a large storage capacity for water. His wells are already 36 ft. deep and further progress is barred by the fact that they now rest on a bed of clay. Under this bed of clay, which has been proved to have a thickness of more than 50 ft. it is not at all improbable that water-bearing sands or gravels may be met with, and it is quite possible that by sinking the bore hole to a sufficient depth we might obtain an artesian or sub-artesian supply of considerable volume.*

In old river beds the sand is often much coarser and yields water very freely. In such places there is but little difficulty in getting sufficient water for pumps of even considerable size. The chief difficulty lies in constructing the wells, which require to be of large dimensions so as to give a sufficient area for percolation. If the wells are small the water level will have to be lowered to produce sufficient flow to feed the pump and the incoming water brings sand with it and speedily fills up the well. A pumping station at a well of this type has recently started work near Villupuram, and a second one will shortly be installed at Pandur, near Trivalur.

Wells which derive their water supply from fissures or springs are extremely numerous in certain parts of the Presidency. Many of them are of great depth and storage

* *Vide* "Irrigation by Artesian Wells."

capacity, but the quantity of water they yield depends entirely upon the nature of the water-bearing fissures which are met with. The volume of water which a well will yield can be measured in the way already described; but beyond the actual figures obtained nothing of any value can be deduced. As a general rule, deepening the well will open new fissures and bring in a larger supply of water, but this is not necessarily always the case, and information obtained from borings furnishes no indication as to what will happen. In some cases holes have been "jumped" at the bottom of these wells with long iron jumpers, and fairly big charges of dynamite have been exploded in them with extremely satisfactory results. New fissures have been opened and a sub-artesian water-supply obtained. As yet we know very little about subterranean water in this Presidency. In course of time the records from pumping stations will add very largely to our information; but in order that we may fully avail ourselves of the water-supply which can be got at a reasonable depth, boring must be carried out on a very extensive scale.

IRRIGATION BY PUMPING—IV. *

THE experiments in irrigation by pumping, now going on in various parts of this Presidency, are an attempt to introduce into the country new methods of working which have been rendered possible by the enormous advances which have been made during recent years in the methods of producing power. The application of the steam-engine to pumping water for irrigation or drainage is no new thing. In some instances it has been done on a large scale. Along the Nile, in Egypt, and in the Western States of America steam-engines and pumps have been largely used for irrigation work; whilst in the Fen Districts of England, in the marshes of Italy, and the low lying tracts of Holland, they have remedied the natural defects of the drainage, and vast quantities of water have raised at a comparatively small cost. In India the steam-engine and pump have been occasionally used both for irrigation and drainage, but, as a rule, the work never proceeded beyond the experimental stage, as the scale on which operations were conducted was too small to make it pay.

Fully five and twenty years ago the Otto gas-engine proved a practical rival to the steam-engine when small amounts of power were required. But such engines could

* *The Madras Mail*, 24th October, 1905.

only be used where a supply of gas was available. The obvious field open to an engine of the internal combustion type which would be independent of a town gas supply, led to the production of the earlier types of oil-engine. One by one the practical difficulties connected with their working were overcome, and for some years past it has been possible to obtain motors suitable for agricultural work which could be placed in the hands of people possessing very little mechanical skill.

As compared with the steam-engine the oil-engine is extremely economical. The smallest size of oil-engine uses no more fuel per brake horse-power developed than the largest and most economical type of steam-engine. The steam-engine will develop power on a large scale very economically in places where coal is cheap, but in small engines, even where fuel is cheap, the efficiency of the process by which the heat of combustion of the fuel is converted into work is so very low that the cost of power generated in them is extremely high. In large engines, a brake horse-power can be developed by burning from 1 to 1¼ lbs. of good coal in the boilers, but in small portable engines, such as are frequently used by contractors for driving centrifugal pumps, the quantity of fuel required per brake horse-power varies from 6 to 10 lbs. On the other hand, small oil-engines can be run with an average expenditure of 1 pint of kerosine oil or liquid fuel per horse-power developed. So long as kerosine oil or liquid fuel were expensive, the advantages of the oil-engine were not apparent; but at the present time kerosine oil can be purchased at from 4 to 8 annas a gallon and liquid

fuel is available in Madras for 2 annas a gallon, or Rs. 30 a ton.

In the beginning the gas-engine was only suited for small powers and was worked with comparatively rich gas. The discovery that an extremely poor gas, which could be manufactured in enormous quantities at a very low rate, could be utilised with advantage in the gas-engine, led to the production of engines of large power; and now at the present day engines up to 5,000 horse-power are being worked with producer gas or the waste gases from blast furnaces. Still more recently it has been discovered that the gas-engine can be combined with a small gas producer, in which the gas is manufactured according to the demand of the engine. These plants, which work on the suction principle, have, within the last two or three years, proved an unqualified success and for all but the smallest powers are likely in the future to be more than rivals of the oil-engine. Unfortunately they require either anthracite coal, coke or charcoal and the ordinary bituminous coal which is available almost everywhere is not suitable.

The items which go to make up the cost of running a pumping plant are—

(1) Fuel.
(2) Stores.
(3) Interest and depreciation.
(4) Repairs.
(5) Superintendence.

And the relative importance of these varies greatly, depending upon the type of motor employed and the local condi-

tions as regards supply of fuel and cost of labour. The reason why irrigation by pumping with the oil-engine is proving successful is due to the fact that not only is the cost of fuel low but the running of the engine can be entrusted to intelligent coolies who have received a little special training. As the demand for oil-engine drivers is steadily growing we have established a training class for them in the School of Arts, and the idea is to supply a course of training lasting for six months, the pupils being sent up to learn the work from the villages in which they will subsequently drive engines. If a fitter is employed to drive an engine he usually requires from Rs. 15 to Rs. 20 a month pay; but if a local man receives sufficient training to run the engine and knows how to keep it clean and in good working order, he will do just as well and will be content with, and in fact will consider himself well off on, Rs. 7 or Rs. 8 a month. At the present time there are about 200 engines of different kinds at work in this Presidency, and the majority of these are, so far as my information goes, in the hands of people who are paid but little more than ordinary coolie wages. At Melrosapuram the engine is in charge of a boy off the farm who was trained in the School of Arts for a few months and he is paid Rs. 6 a month. At Kadiampatti Mr. Andersen pays his drivers Rs. 8 and 7 a month respectively. He has to keep two men because he has a good supply of water and runs his engine for many hours every day, cultivating some 60 or 70 acres of land with a 6½ h. p. engine.

The ease and convenience of oil-engines as a source of power has rendered them extremely popular all over the

world, and there are a large number of manufacturers who make a speciality of these motors. When kerosine oil is used as fuel there is but little to choose between them, the better engines being the more highly priced; but kerosine oil is expensive when compared with the liquid fuel which is available in Madras and which is equally suitable for generating power, if the engines are specially adapted for it. Till some time last year there were only two types of engines on the market which would work satisfactorily with liquid fuel; *viz.*, the Diesel Engine and the Hornsby-Akroyd. The former is undoubtedly the best and most economical oil-engine which has been produced, but its initial cost is very high and it would certainly not be safe to trust it in the hands of the class of people we are employing as oil-engine drivers. Moreover, from a purely commercial point of view the economy in fuel consumption is more than counterbalanced by the extra cost of labour to look after it and by the increased interest charges entailed by its high price; so that for engines of below 40 or 50 horse-power its use is only to be recommended where skilled mechanics must be employed irrespective of the type of engine in use. In the School of Arts we have an 8-horse power Diesel Engine at work which runs very satisfactorily when it is in good working order; but in so small an engine the mechanism of the valves is rather delicate and they are a source of considerable trouble. The manufacturers themselves now recognise that this engine is of too small a size for practical work, and I believe they do not now manufacture engines of less than 20 horse-power.

The Hornsby-Akroyd engine works on a totally different principle and engines of as small as 2 horse-power can be satisfactorily run. Last year the master patent on the engine expired, with the result that the principle of working has now been adopted by many makers of oil-engines; and it is no longer true, as it was last year, that the Hornsby engine is the only one on the market which will work with liquid fuel. When it was selected as the type of engine to be employed in these irrigation experiments, it was the only one available, and though now there are others, it still stands first in the estimation of those who have most to do with them. In 1904, Mr. Dugald Clerk, probably the greatest living authority on oil and gas engines, delivered the James Forest Lecture to the Institution of Civil Engineers, his subject being "Internal Combustion Motors." In the notes appended to his address he remarks as follows regarding the Hornsby heavy oil engine :—

"This engine is the most extensively used of all the 'heavy' oil-engines of the world, Messrs. Hornsby having built many thousands of them in England. The success of this engine shows very clearly that it is often better to be content with a lower heat efficiency in order to obtain a practical engine free from delicacy of construction and easily kept running under the most adverse conditions."

With the new cheap fuel engines of other makers I have no practical experience. Some of them may be as good, but it is certain that none of them are better than the

Hornsby engine, which for the present has been selected as the standard engine to be used in all irrigation pumping installations the funds for which are provided by Government either directly, or through the operation of the Agricultural Loans Act. Not only is there nothing to be gained by introducing a multiplicity of types, but very considerable advantages accrue from the fact that the whole supply is in the hands of one firm. It becomes an important part of their business and it is well worth their while to devote their attention to it, to stock parts which occasionally require renewing and to attend to repairs and breakdowns with the least possible amount of delay. Later on, when pumping engines are in common use all over the Presidency, there will be plenty of room for several types of engine, but at present this is not the case and rapid development is only to be looked for by concentration of effort along one line. It must not be imagined for a single instant that the best results can be got from an oil-engine by a driver who understands no more than the purely mechanical details of working it. A good deal of skill, knowledge and experience are required to set up these oil-engines and to adjust them to their work; but when once adjusted they ought to remain in good running order for a long time. The idea underlying our system of working is that when an engine ceases to work satisfactorily it should be overhauled by a thoroughly skilled and competent mechanic. Our experience during the last two or three years tends to the conclusion that pumping work is exceedingly hard upon an oil-engine, and that unless it is in perfect working order the results are unsatisfactory.

A good deal of useful practical knowledge has been accumulated concerning the working of the Hornsby engine; and in my next article I propose to publish such facts as I think will be of practical use to those concerned with the running of these engines.

IRRIGATION BY PUMPING—V *

THE main reasons which led us to select the Hornsby-Akroyd engine for pumping water for irrigation were (1) the simplicity of the working parts of the engine; (2) the fact that liquid fuel could be used in place of the more expensive kerosine oils; and (3) the general excellence of the design, workmanship and materials of its construction. As in most other oil and gas-engines, the working cycle is effected in two revolutions. At the commencement of the cycle the piston is at the back end of the cylinder, the air valve is open and as the piston moves forward the cylinder is filled with fresh air. At the same time the oil pump injects a jet of fuel into the hot vaporiser behind the piston, where it is converted into vapour. During the return stroke of the piston the air is compressed in the cylinder and driven through the contracted opening between the cylinder and the vaporiser into the vaporiser itself, where it mixes with the oil vapour. The capacity of the vaporiser is so adjusted that when the piston has completed the return stroke, the pressure and temperature of the mixture of oil vapour and air are such that an explosion takes place and the piston moves forward, making the working stroke of the engine. Just before the completion of this stroke the exhaust valve opens

* *The Madras Mail*, 31st October, 1905.

and the burnt gases pass into the exhaust. During the second return stroke, the piston drives out of the cylinder all the burnt gases, and the exhaust valve closes as the air valve opens for the next cycle. It will thus be seen that energy is generated in the engine and work done on the piston during only one stroke out of four. During two strokes the piston is running almost free, and during the fourth stroke it is working against a gradually increasing back pressure. It is obvious, therefore, that a fairly heavy fly wheel is necessary for steady running.

To start the engine, a lamp is used to heat the vaporiser to a temperature just below red-heat. This takes from 5 to 10 minutes, depending on the size of the engine. After that the heat generated by the successive explosions in the cylinder maintains the vaporiser at a sufficiently high temperature. The working parts of the cylinder, and the neck connecting the vaporiser with the cylinder, are kept cool by means of a water jacket, through which water is constantly circulating. The hotter the cylinder the greater is the thermal efficiency, but the smaller is its capacity for doing work, as when the cylinder is very hot a less weight of air is drawn into the cylinder and therefore a less weight of explosive mixture is formed. Provided the vaporiser is kept hot enough to produce a well-timed explosion, the cooler the cylinder the greater the amount of power which can be generated by an engine; and in this country, where it is difficult to obtain cold circulating water, it is desirable to have sufficient water passing through the jackets so that the temperature is not raiseg beyond what is bearable to the hand. With pumpind

installations it is easy to obtain a sufficient supply of water, and instead of employing cooling tanks, as is the common arrangement when oil-engines are used in Workshops and Factories, we generally employ either a small auxiliary pump to force water through the jackets, or, where the irrigation water is raised above the level of the engine cylinder, a branch pipe takes off from a small tank which is kept full by the main pump. A cock or valve on this pipe enables the flow of water through the jackets to be adjusted so as to obtain a satisfactory result.

The liquid fuel we are using in these engines is obtained from Messrs. Best and Co., the local Agents of the Shell Transport and Trading Co. It comes from Borneo, and is similar in character to what is known as *astatki* on the Russian oil-fields. It is the residue which is left after the lighter oils have been removed by distillation. Usually it contains a small percentage of water, which gradually settles at the bottom of the storage tank, and it requires to be carefully filtered before running it into the engine tank. If that is not done the very fine passage through which the oil is squirted into the cylinder invariably chokes with dirt of some kind. This liquid fuel is of high specific gravity and generally ranges between 0·95 and 0·97. A sample which was analysed, proved to have a specific gravity of 0·967, the flashing point was 206° F., and the heating value was 19,050 British thermal units, which is from 5 to 10 per cent. less than that of ordinary kerosine oil.

Our experience with the working of these engines extends altogether over a period of about five years, and we find

that they are subject to very little depreciation on account of wear and tear. Certain parts require from time to time to be renewed, and if this be done the engine remains practically unaffected by use and is as good after five years work as when it was first put in. If the engines are properly looked after, repairs and renewals cost very little; but even when they are badly treated the amount of harm done is surprisingly small. The vaporiser, which is a separate casting bolted on to the back of the cylinder, lasts, when the engine is not overloaded, from one to two years, and then requires to be renewed. In the brasses of the connecting rod there is a certain amount of wear, and they also from time to time require renewal. But when the engines are kept properly cleaned this should be at fairly long intervals. The pump spindle is also subject to wear, especially when the glands are too tightly packed, which will be found to be frequently the case with native drivers: but this is a very small matter. At very long intervals it is probable that the cylinder liner will require renewal, and more frequently it will be necessary to insert new piston rings. None of these items are very costly; and it may be safely said that if an engine is kept in good running order, and renewals made from time to time as they are required, its life will be indefinitely prolonged, and it is hardly necessary to set aside anything for depreciation. When liquid fuel is used in the engine, a deposit of carbon forms in the vaporiser, which it is necessary to remove after about 12 hours running. To enable this to be done easily the back of the vaporiser can be removed by taking off two nuts and the interior exposed to view. When the

engine is properly adjusted to the work which it has to do, and the temperature of the vaporiser is not too high, this deposit of carbon is soft and friable and very easily removed ; but if the engine is allowed to work with a red-hot vaporiser, the carbon deposit is extremely hard and somewhat difficult to detach from the ribs of the vaporiser.

It is extremely important that there should be no air in the pipe between the pump and the spraying nozzle, as this causes a practically continuous stream of oil to dribble into the vaporiser when there ought to be only a short sharp jet lasting for a small fraction of a second, and quite complete before the compression stroke begins. This is a very common defect in the working of these engines and one which gives rise to a great deal of trouble, although it is easily remedied.

In the earlier patterns of engines the clearance space, when the piston is on its back centre, can be varied by altering the effective length of the connecting rod. But in the latter patterns of engine the connecting rod is of fixed length, and a special adjustable cover is provided, whereby the volume of the clearance can be varied. The larger the clearance space, the lower is the compression pressure and the higher the temperature necessary to obtain a satisfactory explosion. In practice we find that with liquid fuel the compression pressure should amount to from 50 to 60 lbs. per square inch to obtain satisfactory results. When this pressure is not reached, a larger quantity of fuel has to be injected into the engine and the temperature of the vaporiser becomes very high. Often when the engine is called upon to develop its maximum working

horse-power the vaporiser gets very hot that the explosions take place before the end of the stroke and a very inconvenient back pressure is set up which seriously diminishes the power of the engine and causes it to lose speed. For reasons which at present I have not succeeded in discovering, some engines are much more liable to overheat the vaporiser than others, and we find that the only effective way of dealing with them is to decrease the heating surface by removing a certain number of the radiating ribs. In every case this has proved a satisfactory cure.

For the pumping installations which we first put down, it was considered desirable to keep the capital outlay as small as possible, and, accordingly, engines were provided which, to do the work required of them, necessitated the generation of their maximum horse-power through the greater part of their running time. Experience has shown that this is not altogether satisfactory and it is desirable to allow a fair margin, as in pumping water the load never varies except that, when emptying a well it gradually increases from start to finish.

The amount of power which can be generated by an oil-engine of a given size is affected very considerably by the height above sea-level of the place in which it is worked, and oil-engines require careful adjustment for the elevation, if the level be more than 2,000 or 3,000 feet above the sea. In the high ranges of hills in Southern India, where oil-engines are used for driving tea factories and coffee pulping machinery, the loss of power due to the rarity of the atmosphere must amount to as much as 20 per cent. even when they are properly adjusted and a sufficient terminal

pressure is reached at the end of the compression stroke. When this is not attained they can never work satisfactorily, and the fuel consumption must always be extremely high. In practical working it is doubtful if the Hornsby engine is quite as economical in fuel consumption as some other types of engine, as the simplicity of the method of ignition is to some extent purchased by sacrificing thermal efficiency. A high compression is conducive to efficiency, but if it exceeds a certain amount in the Hornsby engine, then pre-ignition takes place with bad result.

The practical management of these engines is extremely simple, and can be entrusted to intelligent coolies who have received a short course of instruction. Where the load on the engine varies considerably, it is desirable to vary the stroke of the pump so as to adjust the fuel supply to obtain as nearly as possible an explosion at every stroke. When the engine is working satisfactorily the governor sleeve should be just floating and occasionally the oil supply should be cut off. The lubrication of the engine is a very important matter and a serious item in the total cost of running it. The lubricators should always be kept in good working order and the best oil that is procurable at a reasonable price should be employed. Nothing better than a good mineral oil can be used, but they are comparatively expensive, and an engine can be run fairly well with castor oil for the main bearings and a mixture of cocoanut and kerosine for lubricating the cylinder.

IRRIGATION BY PUMPING—VI.*

THE rivalry between the makers of oil and gas-engines as sources of motive power is keener now than at any previous time and except for very small installations it is difficult to say which is best adapted for pumping water for irrigation. For installations requiring less than 10 h.p. it will, I think, be generally accepted that a cheap fuel engine of the Hornsby type cannot be surpassed wherever liquid fuel can be obtained at a rate not much in excess of Rs. 45 a ton. In the South of India the great majority of our pumping stations will be under 10 h.p and with liquid fuel available in Madras at 2 annas a gallon, or Rs. 30 a ton, there are not many places where it will cost more than Rs. 15 a ton for carriage from Madras. When more than 10 h.p. is required, the gas-engine in conjunction with a suction gas producer using charcoal as fuel is likely in some instances to prove a more satisfactory method of obtaining power.

Many years ago, in the early days of the gas-engine, their use was greatly extended by Mr. Emerson Dowson, who invented a method of manufacturing gas suitable for generating power which was very much cheaper in working than the ordinary coal gas manufactured in towns for illuminating purposes. In his producer a jet of steam under

* *The Madras Mail*, 9th November, 1905.

pressure was introduced beneath the fire bars of a closed furnace, and was arranged so as to serve as an air injector. The mixed air and steam in fairly definite proportions passed between the fire bars and through a mass of incandescent fuel, resulting in the production of large volumes of gas consisting mainly of a mixture of nitrogen, carbon-monoxide and hydrogen. Valueless as an illuminating gas, it was admirably adapted for gas-engines, and the very economical results obtained with it gave a great impulse to their development, and to-day it is employed in a very large number of plants. The system is simple, but it requires a boiler in which steam under a pressure of from 30 to 50 lbs. per square inch is maintained, and a gas holder in which the gas is stored till required. Obviously, therefore, it requires a certain amount of skilled supervision and is not adapted for working on a small scale. The fuel used must be anthracite of a good quality, and this further limits the field in which it can be usefully applied. These disadvantages have been fully recognised by gas-engine makers, and in their efforts to meet the ever increasing competition of oil-engines they have succeeded in making enormous improvement in the methods of manufacturing gas, and have finally succeeded in producing plants which in conjunction with gas-engines are likely to obtain a final victory.

The suction gas producer plants now on the market require no boilers, no gas holders, and can be worked without skilled labour. From an Indian point of view they possess the further advantage that they can easily be manufactured in the country by existing engineering firms,

and they can be worked with charcoal, of which large quantities could be readily furnished by the Forest Department if there was a steady demand for the same. Apart from the possibility of obtaining cheap supplies of liquid fuel from Burma, we are at present entirely dependent upon foreign sources for our oil-engine fuel, and, though it may be a minor matter, yet it is not one to be altogether disregarded, that the suction gas producer solves the problem of obtaining a cheap supply of power without having to go outside the country for the fuel used.

Of suction gas producers the number already on the market is very large; but, like bicycles, there is not much difference between the productions of the various makers, and most of them may be reckoned upon to do satisfactory work. Essentially they consist of a vessel containing water which is kept boiling after the apparatus is once started by the hot gases coming from the furnace. The air, which is drawn in, passes over this water and thence into the closed ash pit of the combustion chamber. Passing through the mass of incandescent fuel the water vapour is decomposed and hydrogen set free. The oxygen of the air and the oxygen from the water combine with the carbon of the fuel and produce carbon-dioxide and carbon-monoxide. The former is valueless, but the latter is the principal source of energy in the resultant mixture of gases. From the combustion chamber the hot gases are drawn round the boiler already mentioned into a coke scrubber, where the dust and solid particles are removed by the action of water continuously trickling over the coke. A tar separator follows and then the gases pass to a small reservoir,

generally known as the anti-fluctuator, and thence to the gas-engine. To start the manufacture of gas, a small hand fan is provided to drive the air through the apparatus; and the products of combustion are allowed to escape past a valve into the chimney, till the apparatus is beginning to yield gas of sufficiently good quality to drive the engine. The hand fan is then stopped, the valve to the chimney closed, and the engine started. Thenceforth, air is drawn through the producer by the suction action of the piston of the gas-engine, and the quantity of gas generated is exactly that required to meet the demands of the engine. Within moderate limits, the variations in demand cause no trouble, but if the load is very variable, the gas producers do not work very satisfactorily. Pumping water is almost an ideal load, as it remains either constant or is a steadily increasing one. In the producer apparatus, when at work, the pressure is always less than atmospheric; there is therefore no danger of escaping gases, and the steam generator being at the same pressure is in no way a source of danger if neglected.

The usual fuel is anthracite, but where this cannot be obtained at any reasonable price, good hard coke or charcoal may be employed. The gas producer must be looked upon as part of the power-generating plant, and for any given size of engine the producer must be of corresponding capacity. It is possible to obtain these suction gas plants of very small size, but they are much more costly than oil-engines of corresponding power, and it is doubtful if they are so economical. The lowest limit of size seems to be about 10 horse-power, and the largest at present in use

are capable of generating about 300 horse-power. With anthracite coal, the consumption of fuel per brake horse-power is extremely small, and in practical working medium sized plants may be safely reckoned upon to yield one brake horse-power per pound of anthracite, or per pound and a quarter of coke. Properly carbonised charcoal will give about the same results as good coke, and it will be a safe estimate to assume the one ton of good charcoal will give 1,500 b. h. p. hours. The cost of charcoal in India varies a good deal. In Madras at the present time it is about Rs. 25 a ton, but in large quantities it will probably be possible to secure a supply for Rs. 20 a ton.

Some years ago there was a discussion as to the possibility of manufacturing iron in the Salem District from charcoal, and Mr. C. W. Brasier, who was then Forest Officer in that District, estimated that charcoal could be manufactured on a fairly large scale and delivered at a distance of ten miles for Rs. 8–8 a ton. This is probably a sanguine estimate, but there is very little doubt that in most parts of the Madras Presidency it would be possible to obtain charcoal at Rs. 15 a ton if there were a steady demand for it. This means that for one rupee we can obtain 100 brake horse-power hours. Using liquid fuel in an engine of about the same capacity, we could hardly expect to work with less consumption per brake horse-power hour than four-fifths of a pint. This would mean that 100 brake horse-power hours would require 80 pints or 10 gallons of liquid fuel, which in Madras would cost Rs. 1-4-0 and in most places Rs. 2.

Roughly, therefore, we may say that a suction gas producer plant for fuel costs about one-half that of a Hornsby oil-engine. The other items which go to make up the sum total of the working expenses are not very different in either case, though the capital outlay for a suction gas producer plant and gas-engine is about 20 per cent. greater.

It will thus be seen that the popularity of the suction gas producer rests upon a thoroughly sound basis, and although as yet but few of them have reached India, any one requiring power, whether in small or large quantities, would be very ill-advised not to consider the claims of this comparatively new method of obtaining gas suitable for motive purposes. Within the last few weeks a plant of this description has been installed in the Mount Road to drive a dynamo for electric lighting work. Since it was started I have had it under careful observation, and I have come to the conclusion that it can be run as easily as an oil-engine at a slightly smaller cost.

As a typical instance where a suction gas producer plant can be installed with advantage I may cite a case which was recently under investigation. At the foot of the hills in the Godavery District a natural lake of considerable extent has been formed by the gradual closing up of the mouth of a lateral valley by silt deposited during floods in the river. It is estimated that this lake is capable of supplying sufficient water for 500 acres of land, and I have recommended the installation of engines and pumps to lift the water out of the lake to a height sufficient to command the land. Three sources of motive power were practicable, (1) Diesel engines, (2) Hornsby oil-engines, and (3) gas-

engines. The third was finally selected because it involved the owner of the land in the smallest annual outlay. Within a short distance from the pumping station are situated considerable tracts of forest land which belong to him and from which he can obtain supplies of charcoal at a very low cost. By working his forest systematically he can obtain enough charcoal from an acre of land to supply power sufficient for an acre irrigation. This is a very satisfactory result, as there is scarcely any doubt that the forest land will greatly improve by systematic felling. The suction gas producer is comparatively new to India, but there is scarcely any doubt that it has a great future in front of it.

IRRIGATION BY PUMPING—VII.*

CONCLUSION.

BEFORE concluding the series of articles on Irrigation by Pumping, it is necessary to discuss briefly the methods by which the power generated is actually applied to lifting water. This part of the business is open to treatment in great detail. But the discussion is mainly one for technical papers and is not susceptible of popular treatment. The simplest and cheapest method of lifting water is by means of the centrifugal pump. But, unfortunately, the centrifugal pump as ordinarily installed is by no means an efficient machine. The loss of power ranges from 60 per cent. in pumps with a 3 in. suction pipe to 45 per cent. in pumps with a suction pipe 10 or 12 inches in diameter. More favourable results than this are frequently claimed by makers of centrifugal pumps, but it is doubtful if in ordinary practical working they are ever realised. A centrifugal pump with a 2 in. suction pipe would be a most convenient size to employ on a very large number of wells in this country. But the efficiency is extremely low, and on a lift of 30ft. probably three-fourths of the power put into the pump would be wasted. The centrifugal pump as an irrigation machine has never been studied with sufficient care, but it is likely that this

* *The Madras Mail*, 17th November, 1905.

omission will be remedied in the immediate future as both in California and India the matter has been taken up and a great deal of preliminary work done.

Of the loss of energy which occurs in centrifugal pumps when they are worked, part is lost in the pump chamber itself, and part in the suction and delivery pipes ; and the proportion that the latter bears to the former is often a considerable one. Where the level of the water which has to be lifted fluctuates a great deal, the ordinary centrifugal pump can only deal with it when the range of level is not greater than the suction height of the pump. In ordinary practice this is limited to 20 ft., but if the foot valve is carefully designed so as to present but little obstruction to the flow of water and if the suction pipe is of sufficient diameter to carry the water at a moderate velocity, it is possible to work with the suction length as great as 28 ft. For instance, the ordinary 3 in. pump has a 3 in. suction pipe, and the pump should be placed not more than 22 ft. above the minimum water level. But if a 4 in. pipe be employed with the same pump, the suction height can be increased to as much as 28 ft. and the loss of energy in working the pump correspondingly decreased. In many wells in the South of India the level of water fluctuates a great deal more than this and may amount to as much as 50 or 60 ft. In such cases it is most convenient to use a centrifugal pump with a horizontal propeller supplied with power through a vertical shaft. Such pumps may be employed with a suction pipe from 25 to 28ft. long and can therefore be easily fixed when the water is moderately low and they will work perfectly satisfactorily

when submerged. The engine is placed near the mouth of the well and the vertical shaft in the pump carries a pulley fixed in position so that it con be driven by the engine through a quarter twist belt. This arrangement is somewhat expensive on account of the necessity of keeping the shaft in perfect alignment; but it is very simple and the cheapest way of dealing with large quantities of water. In America, where water is often raised from great depths, the vertical shaft and the horizontal pump are very commonly employed with the best possible results, and in not a few cases the shaft is driven by an electric motor either mounted direct on the upper end of the shaft or at some little distance off and driven through a quarter twist belt.

Where the quantity of water to be lifted is not very large, bucket pumps might be employed with great advantage. In this matter also we must look to America mainly for examples to copy. English practice in the matter of pumps is exceedingly good and substantial, but it is generally too expensive. What is wanted in this country is for the local engineers to manufacture a class of pumping machinery which avoids the flimsiness so frequently apparent in American designs without running to the other extreme, as is the case with English makers. It is inevitable with pumps of this type that they should be expensive and heavy when compared with centrifugal pumps; but, on the other hand, this advantage is to a large extent compensated for by their superior efficiency, as it is not difficult with a lift of 40 ft. or more to obtain a return in the water lifted of 80 per cent. of the energy put into them. That such pumps have not been

used hitherto is mainly due to the fact that they require a good deal more skill in the design and erection of them. But now that the matter has been taken up by Government, it is reasonable to hope that this difficulty will disappear. In selecting a pump for irrigation work, the question of efficiency is of extreme importance. It is often better to pay two or three times as much for a more efficient pump, as it means that a smaller engine can be used to drive it and the saving in cost of the engine may be sufficient to pay for the extra cost of the pump. The final result is that the working expenses are diminished by the smaller amount of power which has to be generated to drive the more efficient pump.

The majority of wells in this country do not yield a sufficient supply of water to make it worth while employing engines and pumps; and, as in most places where well irrigation is extensively carried on, there are numerous wells in close proximity to one another; it has been frequently suggested that it would be profitable to employ a portable engine and pump, which might make a daily round, lifting out the water from a number of wells. This is by no means impossible; but the plant will be costly and will require skilled men to supervise it, so that it is hardly likely that it could be done with any profit.

A more practicable plan, but one which has not yet been tried in this country, will be to put down a central power station and distribute energy to a considerable number of wells in the neighbourhood. There are at least three ways in which this could be done.

(1) On the oil fields in America it is a common practice to work a number of deep well pumps by wire ropes attached to a large eccentric driven by an oil or steam-engine. On the Kern Valley Oil Field in Southern California I saw in some instances the pumps of more than a dozen wells being driven by one centrally situated engine, which, through a pair of bevel wheels, drove a vertical shaft carrying two eccentrics, to the sheaves of which wire ropes radiating in all directions were attached. The shaft made about 15 revolutions a minute, and the eccentric throw being about 12 inches gave the pump a stroke of 2ft. The wires were suspended in slings attached to cross arms on wooden poles and the pumps could be worked satisfactorily up to a distance of half a mile from the engine. It will not be difficult to adapt this system to well irrigation in India, and there are hundreds of places where clusters of wells could easily be found and from which sufficient water could be obtained to give employment to engines of considerable power.

(2) Electric motors and pumps might be installed in each well and the energy supplied to them from a central power station. This system is hardly applicable on a small scale but could be used with great advantage where there are a large number of wells.

(3) At a central power station the engines might be used to drive air compressors and the power distributed through pipes to wells, in each of which would be installed a Pohle air-lift. This system is better adapted to tube wells which are carried to a great depth. But it is also possible to adapt it to wells sunk in beds of sand where the fluctuations in

the water level at different seasons of the year are not very great. The air-lift is extremely simple, and if properly designed, is fairly efficient. It has been extensively used both in Europe and America ; and under certain conditions it might be advantageously employed in irrigation work.

Irrigation by Pumping in India is in its infancy, and it can hardly yet be said to be out of the experimental stage. But that does not mean that it is unprofitable. I do not know how many pumping installations for irrigation work exist at the present time in India, but in Madras Presidency since the beginning of last year about 25 separate plants consisting of oil-engines and centrifugal pumps have been installed either directly or indirectly through the operation of the special Department which has been created to develop this kind of irrigation. These 25 engines involve a total of 190 horse-power and are capable of irrigating 1,260 acres of land, the value of the crops grown on which may be estimated at Rs. 1,25,000. This is a small beginning, but the work is steadily growing and there is no doubt that eventually mechanical means for lifting water for irrigation will be extensively employed in every part of India where the conditions are favourable.

THE VALUE OF WIND-MILLS IN INDIA.*

PREVIOUS to the advent of the steam-engine the wind-mill was held in high repute as a means of obtaining motive power, and it was largely used for grinding corn and for raising water for the drainage of low lands. The old fashioned mill was cumbrous and expensive, and, as a rule, it was so heavily loaded that it only worked in strong winds. The disadvantages attendant on its use were many and serious and it is not surprising that it fell into disrepute. Subsequently the invention of the dynamo and the electrical accumulator again drew the attention of Engineers to the wind as a source of energy and the modern aermotor or wind-engine was gradually developed. The expectations based upon the conversion of the power of wind into electrical energy and its storage in accumulators have not been realized mainly because of the large capital outlay involved in the plan. But a very large field for the use of wind-engines has been found in employing them to pump water either for domestic purposes, for drainage or for irrigation, and at the present day many thousands are doing useful work in these directions. In no part of the

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world is there more scope for them than in India where millions of cattle are daily employed in raising water from wells for the irrigation of land, but unfortunately, they are too expensive for the individual ryot, and there is a generally prevalent idea that the wind-currents in India are too light to make the amount of energy derivable from them of any material value.

About two years ago I was asked by the Board of Revenue to furnish them with information regarding the utility of wind-mills for irrigation work, and, as there was no trustworthy information available, I proposed to Messrs. Parry & Co., the Madras Agents of the Chicago Aermotor Company, that, if they would place an aermotor at my disposal for purely experimental work, I would undertake to collect and place on record the observations. After consultation with their principals in America, it was settled that a 16 ft. aermotor mounted on a 70 ft. tower should be handed over to me to experiment with and the Board of Revenue agreed to furnish the necessary funds.

A new aermotor was accordingly sent out, and I had it put up in the compound of the School of Arts, Madras. An attempt was made to sink a well, but the sub-soil proved so unsatisfactory that the well was abandoned and a masonry tank 10 ft. square and 5 ft. deep was constructed under the aermotor tower. It was originally intended that the aermotor should drive a rocking lever at the ground level, to which lever two pumps rods were to be attached, one working an 8 in. pump, the other a 6 in. pump, both to be fixed 25 ft.

below ground level in the well. But when the well had to be given up it was found impracticable to arrange for driving two pumps except at a greater expense than was warranted and only the 8 in. pump was fixed in the tank.

The object of the experiment was to ascertain the quantity of water which the wind-mill would lift to a certain height every day in the year, and as there was no necessity to use the water for any purpose it was decided that the pump should be arranged to lift the water 25 ft. and allow it to fall back into the tank. To obtain the information required, a tacheometer was fitted to the pump to record every stroke, and to obtain the quantities of water lifted, it was only necessary to ascertain, as accurately as possible, the delivery of water per stroke. To do this, another tank 10 ft. square and 5 ft. deep was built above the level of the ground and the water discharged from the delivery pipe was carried to it by a two-inch main fitted to the bottom of a wooden funnel into which the water lifted by the pump was discharged.

The aermotor and tower were bolted together horizontally on the ground and were then lifted into a vertical position by means of a derrick. The plan followed was the very ingenious one devised by the Aermotor Company, but it gave us a great deal of trouble, as the tower, though it has proved to be amply strong enough in the erect position, was not well adapted to resist the strains brought upon it during the process of lifting, notwithstanding the fact that the instructions of the Aermotor Company were carefully carried out in regard to the addition of temporary bracing

to resist the bending stresses. The wind-wheel was geared down to work the pump in the ratio of $3\frac{1}{3}$ to 1. The diameter of the pump was 8 inches and the length of the stroke 16 inches, so that the theoretic discharge of the pump was 2·9 gallons per stroke. Careful experiments repeated a great number of times by recording the number of strokes required to fill the measuring tank showed that the average quantity of water delivered by each stroke of the pump was 2·5 gallons or 86 per cent. of the theoretic delivery. After preliminary experiments a daily record of the work done by the wind-mill was kept from the end of March 1902, and readings of the tacheometer were taken every morning at 8 A.M., at mid-day and at 4 P.M. It was at first intended to set up an anemometer to record wind velocities, but after careful consideration of the matter it was finally decided to dispense with the anemometer readings and to obtain all the information regarding the wind movements from the Observatory in Madras which is situated not much more than a mile away. The aermotor was 70 ft. above the ground and well above the influence of obstructions to the wind caused by buildings and trees, and as the whole country, for miles round, is a practically dead level plain, it was thought that, considering the observations were to be extended over a long period of time, it would be better to accept the Observatory anemometric determinations than to admit a new set with instruments not so carefully calibrated as those of the Government Observatory.

The aermotor has now been in operation for more than one year and sufficient information has been obtained to decide the question as to the suitability of these machines

for irrigation work in India. Mr. R. Ll. Jones, the Deputy Director in charge of the Madras Observatory, has been kind enough to furnish me with a copy of the Observatory wind records for the whole year, and this statement gives not only the daily wind velocity in miles but also the movement of the wind in miles for every hour throughout the year. He has also been kind enough to furnish me with other data regarding wind movements in India of which, as will be subsequently seen, considerable use has been made in this paper and I am greatly indebted to him for his courtesy in this matter. Mr. J. Cook, of the Central College, Bangalore, and Director of Meteorology in Mysore, has also been kind enough to send me valuable extracts from the records of his Observatories, and I am glad to acknowledge my indebtedness to him for the same.

It seems unnecessary to publish the whole of the data which have been collected, but as a sample of the records for the whole year, Table I summarizes the results of the observations made during the month of June.

To determine the ratio between the work done by the wind-mill and the daily velocity of the wind in miles was the main object of the experiments and this was easily done by plotting the observations on section paper, taking as ordinates the number of gallons of water lifted 25 ft. per day and as abscissæ the wind movement in miles per day. When the observations had all been plotted, it was found that a straight line having the equation $X = 175 \ (Y - 53)$ represented the results very satisfactorily, where X is equal to the number of gallons of water lifted 25 ft. per day and Y is the daily movement of the wind in miles.

Table I.

(*Observations made during the month of June.*)

To face p. 92.

Date.	Hour.	Number of strokes of pump during interval.	Number of strokes of pump per day.	Wind movement in miles during interval.	Wind movement in miles per day.
1	Noon.				
	4 P.M.	2,022		39	
2	8 A.M.	5,246		105	
	Noon.	2,028		40	
	4 P.M.	3,783	16,220	50	269
3	8 A.M.	10,409		179	
	Noon.	3.059		47	
	4 P.M.	3,718	17,412	60	283
4	8 A.M.	10,635		176	
6	4 P.M.				
7	8 A.M.	7,912		142	
	Noon	2,880		49	
	4 P.M.	1,029		42	
9	8 A.M.				
	Noon.	2,656		54	
	4 P.M.	3,453	16,003	54	277
10	8 A.M.	9,894		169	
	Noon.	1,626		55	
	4 P.M.	3,501	14,492	56	261
11	8 A.M.	9,365		150	
12	Noon,				
	4 P.M.	2,730		35	
13	8 A.M.	6,982		132	
	Noon.	2,498		53	
	4 P.M.	2,883	8,309	48	182
14	8 A.M.	3.228		81	
	Noon.	3,023		58	
	4 P.M.	3,403	9,561	48	185
15	8 A.M.	3,135		79	
	Noon.	3,350		62	
	4 P M.	2,732	8,141	44	171
16	8 A.M.	2,059		65	
	Noon.	1,886		39	
	4 P.M.	2,384	8,509	46	187
17	8 A.M.	4,239		102	
	Noon.	1,054		36	
	4 P.M.	1,460	7,247	29	169
18	8 A.M.	4,733		104	
	Noon.	1,227		29	
	4 P.M.	1,781	8,720	35	181
19	8 A.M.	5,712		117	

Date.	Hour.	Number of strokes of pump during interval.	Number of strokes pump per day.	Wind movement in miles during interval.	Wind movement in miles per day.
	Noon.	1,220		30	
	4 P.M.	1,188	8,755	34	196
20	8 A.M.	6,347		132	
	Noon.	1,827		34	
	4 P.M.	929	4,621	19	134
21	8 A.M.	1,872		81	
	Noon.	1,838		36	
	4 P.M.	830	7,478	32	197
22	8 A.M.	4,810		129	
	Noon.	2,562		54	
	4 P.M.	1,598	8,176	31	189
23	8 A.M.	4,016		104	
	Noon.				
	4 P.M.	668		23	
24	8 A.M.	4,773		115	
	Noon.	1,793		35	
	4 P.M.	2,262	12,720	41	226
25	8 A.M	8,665		150	
	Noon.	2,154		42	
	4 P.M.	2,707	12,971	47	230
26	8 A.M.	8,110		141	
	Noon.	1,590		37	
	4 P.M.	2,514	11,582	43	221
27	8 A.M.	7,478		141	
	Noon.	1,737		40	
	4 P.M.				
28	8 A.M.	7,003		127	
	Noon.	1,350		41	
	4 P.M.	1,631	6,968	38	179
29	8 A.M.	3,287		100	
	Noon.	2,702		56	
	4 P.M.	4,325	13,621	58	243
30	8 A.M.	6,594		129	
	Noon.	1,103		31	
	4 P.M.	2,906	8,802	44	182
1st July	8 A.M.	4,793		107	

General observations of the working of the wind-mill show that the strongest and steadiest winds generally blow in Madras from noon till about 5 o'clock in the afternoon, and from an examination of the Observatory records, it was found that, on a considerable number of afternoons during the year, the wind blew with an almost constant hourly velocity, and from a selection of such days, a second curve was plotted having as ordinates the work done by the wind-mill from 12 to 4 P.M. and as abscissæ the total wind movement during that period. The equation $X = 156{\cdot}87\ Y$ represents these results with very great accuracy whenever the wind velocity averages more than 8 miles per hour during the period. Careful observations on several days with an anemometer fixed to the wind-mill tower showed that it required a steady breeze of about $7\frac{1}{2}$ miles per hour to keep the wind-mill in continuous motion, but that, when the wind volocity exceeded 3 miles per hour, a certain amount of work was done as the result of puffs of wind. From the first equation it will be seen that, when the daily wind velocity is below 53 miles per day, the amount of work done by the wind-mill is negligible, but that above that velocity it steadily increases in direct proportion to the increased rate of the movement of the wind. This same result is also obtained from the second equation, and it is one of extreme importance because makers of wind-mills invariably claim that the work done by a wind-mill is proportional to the cube of the wind velocity; and in their catalogues and price lists they publish fictitious tables showing the work done by the wind at various velocities.

Table II has been compiled from the average wind velocities measured at the Observatory in Madrs during the 30 years 1864—1894, using equation (1) to determine the average amount of water which the wind-mill can lift.

The other columns in this table show (1) the depth to which an acre of land would be covered during the month by the water lifted by the wind-mill; (2) the average monthly rainfall; and (3) the depth of water which would be supplied to 10 acres of land by adding to the natural rainfall the quantity of water lifted by the pump. The months of February and October are the least windy in the year but during the former the harvest is in general progress whilst during the latter the rainfall is usually heavy. In March and April there is practically no rain, but the water delivered by the wind-mill would be more than sufficient for the seed-beds required for an area of over 10 acres. During May, June and July strong winds are prevalent and the water lifted by the wind-mill added to the average rainfall would cover a field of 10 acres to a depth of over 6 inches. This is sufficient with careful use for the irrigation of almost any crop, and I am therefore of opinion that a 16 ft. aermotor will do sufficient work in Madras to irrigate 10 acres of land when the water has to be lifted 25 ft.

TABLE II.

Month.	Wind; daily velocity in miles.	Rainfall in inches during the month.	Gallons of water lifted per day 25 feet.	Inches, depth on 10 acres per month.	Total rainfall and water lifted inches on 10 acres.
January ...	144	0·89	15,920	2·18	3·07
February ...	122	0·28	12,070	1·49	1·77
March ...	152	0·39	17,318	2·37	2·76
April ...	191	0·62	24,140	3·20	3·82
May ...	227	2·12	30,450	4·09	6·21
June ...	220	2·11	29,215	3·87	5·98
July ...	198	3·87	25,380	2·47	7·34
August ...	174	4·56	21,180	2·89	7·45
September ...	156	4·69	18,020	2·39	7·08
October ...	123	11·00	12,240	1·62	12·62
November ...	165	13·21	19,600	2·60	15·81
December ...	183	5·28	22,740	3·11	8·39

Before discussing these results further, it will be well to give a brief *resume* of the results of experiments on windmills which have been made in other parts of the world. "The Water Supply and Irrigation Papers," published by the United States Geological Survey No. 20, give an account of an extensive series of experiments with windmills made by Mr. Thomas Perry. The experiments were carried out with extreme accuracy and with very elaborate apparatus and the results of them may be summarized as follows :—

(1) The maximum work which can be done by a windmill is proportional to the cube of the wind velocity.

(2) The starting power of a wind-mill is proportional to the square of the wind velocity.

(3) The speed of an unloaded wheel increases in a somewhat greater ratio than the velocity of the wind, but

for practical purposes there will be but little error in assuming that the unloaded wheel revolves at a speed proportional to the wind velocity.

(4) The best speed for a wind-mill is from 0·55 to 0·70 the speed at which it runs when unloaded.

(5) The best load for a wind-mill at any given velocity of the wind is from one-half to two-thirds the maximum starting force at the velocity of that wind.

A large number of experiments were made to determine the best form for the vanes of a wind-mill and the best result obtained showed that a 12-ft. wheel having an area of 113 sq. ft. developed 6,836 foot-pounds of work in a ten-mile wind, or, in other words, that a 12 ft. wind-mill could be made to develop 0·207 H.P. in a ten-mile wind. This result is corroborated by experiments conducted in Denmark at the Government Experimental wind-mill erected at Askov. There it was found that the best result that could be obtained, when applied to a 12-ft. wind-mill would give 0·234 H.P. in a ten-mile wind. These results can be very approximately expressed in the following way. *The maximum work which can be done by a wind-mill in a ten-mile breeze is equal to one foot-pound per second per square foot of wind surface.* A 16 ft. wind-wheel has an area of 201 sq. ft. and should therefore supply in a ten-mile wind 201 foot-pounds of work per second equivalent to 0·373 H.P. From the equation $X = 156{\cdot}87\ Y$, it is found that the actual work represented by the water lifted is 0·198 H.P. or 53 per cent. of the maximum work that can be obtained from the wind. Allowing for the friction of the gearing and the loss of energy in the pump, the

efficiency is satisfactory and the load on the pump is evidently suitable.

A careful consideration of these results leads to several very important conclusions which are entirely confirmed by the experiments on the aermotor. Although the maximum work which can be done by a wind-mill is proportional to the cube of the wind velocity, the actual amount of work which it does when pumping water is proportional to the wind velocity, because the work done depends upon the number of strokes of the pump, and the number of strokes of the pump depends upon the velocity of rotation of the wind-mill, and this, we have seen, is approximately proportional to the wind velocity. This result is fully borne out by these experiments since the work done by aermotor is found to be exactly proportional to the wind velocity. A similar result was obtained by Mr. W. H. Moreland, I.C.S., the Director of the Department of Land Records and Agriculture in the United Provinces, who, in " A Note on Trials of an Aermotor in Well Irrigation" published as bulletin No. II of the Agricultural Series of his Department, gives a table on page 3 which shows that the quantity of water raised at different velocities of wind was approximately proportional to the wind velocity. The practical meaning of this is that the wind-mill works with the greatest efficiency when the velocity of the wind is just sufficient to keep it in steady motion, and, that at any other higher velocity of the wind only a portion of the useful work which the wind-mill could do is utilized. If a convenient arrangement could be devised whereby the load put

upon the wind-mill varied with the square of the wind velocity the work done by these machines would be much greater. An attempt to realize this is made by the Chicago Aremotor Company who provide means whereby three different lengths of stroke of pump can be obtained, but in practice, it is found inconvenient to alter the length of the stroke. The most satisfactory way to vary the load on a *wind-mill is to provide it with two pumps worked through a rocking lever fixed at ground level. One pump can be permanently attached to the rocking lever and the other whenever the wind velocity is sufficient to justify doing so.

Table II has been compiled from the results obtained with a single pump of 8 inches diameter and 16 inches stroke, but it is certain that for the greater part of the year for several hours each day the aermotor would have been capable of working two such pumps with practically no loss of speed.

Table III gives the mean hourly movement of wind at Madras irrespective of direction and by using this table we can approximately estimate what extra work would have been done if it had been possible to attach a second 8 inch pump to the wind-mill whenever the velocity of the wind was sufficient to drive two pumps. With a wind velocity of 8 miles per hour and one 8 inch pump the wind-mill works steadily; with double the load, since the power of the wind-mill is proportional to the cube of the velocity of the wind, a wind velocity of 10·08 miles per hour would be required.

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* A wind-mill has since been erected at Melrosapuram in which the pump is worked through a rocking lever and the point of attachment of the pump rod to the rocking lever can be shifted by a traversing screw. In this way the stroke of the pump can be altered through a range slightly more than double the minimum.

TABLE III.—*Mean hourly air movement of Madras (irrespective of direction).*

———	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Mid— 1 ...	3·70	2·68	3·34	4·94	8·45	8·37	7·64	7·19	5·68	3·18	4·78	4·62
1— 2 ...	3·37	2·48	2·93	4·10	7·90	8·42	7·56	7·25	6·00	3·20	4·59	4·49
2— 3 ...	3·22	2·30	2·58	3·62	7·45	8·09	7·23	6·61	6·01	3·40	4·47	4·28
3— 4 ...	3·15	2·28	2·52	3·41	7·21	8·01	6·86	6·51	6·02	3·55	4·73	4·04
4— 5 ...	3·03	2·15	2·67	3·29	6·97	7·64	6·70	6·08	5·83	3·33	4·70	3·99
5— 6 ...	3·00	2·20	2·53	3·16	6·84	7·17	6·33	5·77	5·53	3·24	4·52	4·08
6— 7 ...	3·09	2·21	2·55	3·87	7·52	7·54	6·26	5·68	5·68	3·45	4·64	4·15
7— 8 ...	3·43	2·82	4·16	6·92	9·82	9·34	8·02	6·85	7·08	4·60	5·59	5·15
8— 9 ...	5·51	4·67	6·41	8·92	10·62	11·14	9·83	8·44	8·64	5·68	7·13	7·37
9—10 ...	7·66	6·38	7·78	9·86	10·78	12·28	11·21	9·51	9·54	6·43	8·72	9·72
10—11 ...	9·27	7·45	8·77	10·91	10·80	12·63	11·90	10·10	9·54	7·18	9·96	11·11
11—Noon ...	10·11	8·43	10·14	12·53	11·76	12·72	11·97	10·12	9·56	7·59	10·77	12·01
Noon—13 ...	10·43	9·29	10·86	13·41	12·36	12·33	11·45	9·90	9·34	8·11	11·20	12·35
13—14 ...	11·13	10·06	11·68	14·16	13·31	12·51	11·42	9·97	9·21	8·64	11·38	12·69
14—15 ...	11·14	10·22	11·91	14·05	13·44	12·46	10·90	9·63	9·10	8·75	11·33	12·45
15—16 ...	11·04	10·14	11·91	13·89	13·31	12·09	10·59	9·15	8·53	8·49	11·28	12·25
16—17 ...	10·37	9·81	11·24	13·07	12·48	11·18	9·64	8·02	7·66	7·76	10·14	11·24
17—18 ...	8·75	8·50	9·70	11·14	11·59	10·18	8·77	7·35	6·26	5·84	8·21	9·03
18—19 ...	6·57	6·37	7·43	9·41	10·40	9·42	7·94	6·27	5·06	4·58	7·05	7·28
19—20 ...	5·86	5·43	6·53	8·40	10·03	9·00	7·86	5·95	5·13	4·07	6·58	6·74
20—21 ...	5·34	4·87	5·89	7·83	9·81	8·90	7·89	6·10	4·98	3·66	5·98	6·34
21—22 ...	4·91	4·48	5·41	7·22	9·70	8·80	8·09	6·71	4·91	3·44	5·68	5·92
22—23 ...	4·43	3·68	4·78	6·48	9·33	8·67	7·69	7·01	5·30	3·22	5·33	5·50
23—Mid. ...	4·07	3·30	4·09	5·86	8·86	8·43	7·57	7·26	5·65	3·24	4·95	5·11

From Table III, Table IV has been compiled by taking out for each month the average number of hours in the month during which the wind velocity was over 8 miles per hour, and also the number of hours in each month during which the wind velocity averaged over 10·08 miles per hour. From the totals it will be seen that the wind was strong enough during 3,791 hours to drive one pump and sufficiently strong during 1,985 hours to drive two pumps. This means, that, neglecting any work done by the wind when the average velocity was below 8 miles per hour, the total quantity of water raised by the wind-mill during the year would have been increased by 52·4 per cent. if another pump could have been attached when the wind was favourable. To drive three pumps the wind velocity would have to be 11·54 miles per hour and the table shows that this velocity was exceeded during 917 hours in the year, so that the addition of a third pump would have increased the work done by a further 24·3 per cent. If a 10 inch pump had been attached to the wind-mill instead of an 8 inch pump, a wind velocity of 9·28 miles per hour would have been required.

Table IV shows that during the year the wind exceeded this velocity during 2,795 hours and the quantity of water which would have been lifted by the 10 inch pump would have been almost exactly equal to that which was lifted by the 8 inch pump, as when the 10 inch pump is working, it will in any given time lift 1·345 times as much water as the 8 inch pump. An examination of the figures given in Table IV shows that with the 8 inch pump the volume of water lifted is more uniformly distri-

PUDUKOTA*.

TABLE IV.

Number of hours in each month the wind movement per hour exceeded 8 *miles* (A), *exceeded* 10·08 *miles* (B), *exceeded* 11·54 *miles* (C), *exceeded* 9·28 *miles* (D).

Month.	A	B	C	D
January ...	248	186	...	217
February ...	196	56	...	140
March ...	248	186	93	217
April ...	360	240	180	360
May	558	341	217	496
June ...	630	300	210	360
July ...	372	217	62	279
August ...	279	62	...	186
September ...	240	...	...	120
October ...	120	...	...	...
November ...	270	180	...	283
December ...	270	217	155	363
Total ...	3,791	1,985	917	2,795

buted throughout the year than would be the case if the larger pump were used, and we may fairly assume that an 8 inch pump is more suitable for work with a 16 feet aermotor in Madras than a 10 inch pump would be. It is important to notice, however, that the difference is not very material and that, in places where the wind distribution is anything like that at Madras, the size of the pump may vary within considerable limits without materially affecting the quantity of water which would be lifted.

Table V extracted from the Mysore Meterological papers gives the mean hourly velocity during the four years (1895 to 1898) at Bangalore, and from this table we have

TABLE V.—*Mean hourly wind velocity—Bangalore.**

		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Mid—1	...	9·5	9·5	8·2	7·4	10·2	12·2	12·3	10·5	8·3	6·8	7·2	8·7
1—2	...	9·0	8·4	7·3	6·9	10·1	11·9	12·2	10·5	7·8	6·3	6·9	8·5
2—3	...	8·7	7·9	6·5	6·7	9·9	11·6	11·9	10·3	7·5	6·1	6·8	8·3
3—4	...	8·5	7·6	6·1	6·2	9·1	11·5	12·0	10·1	7·3	5·8	6·4	8·2
4—5	...	8·1	7·2	5·7	5·9	8·7	11·1	11·8	9·8	8·0	5·6	6·3	8·0
5—6	...	7·9	6·7	5·2	5·4	8·6	10·9	11·6	9·8	6·7	5·2	6·2	8·4
6—7	...	7·8	6·4	5·1	5·8	8·7	11·4	12·1	10·0	6·9	5·6	6·1	8·4
7—8	...	8·4	7·2	6·2	7·0	9·8	12·9	13·5	11·4	8·2	7·1	7·8	10·3
8—9	...	10·5	9·0	7·8	7·3	9·9	14·4	15·1	12·6	8·9	8·2	9·4	12·5
9—10	...	11·0	10·5	8·8	7·4	10·1	15·2	16·1	13·7	9·4	8·5	10·2	12·9
10—11	...	11·7	11·3	9·8	7·5	9·9	16·0	17·3	14·3	9·8	8·9	10·6	13·0

11—Noon ...	11·6	11·4	10·1	8·0	9·8	16·3	17·8	14·5	10·0	9·2	10·2	12·9
Noon—13 ...	11·3	11·3	11·0	9·1	9·5	16·3	17·8	14·5	9·8	9·1	9·8	12·4
13—14 ...	11·3	11·6	11·6	9·7	9·3	16·3	18·1	14·4	9·6	9·1	9·8	12·1
14—15 ...	11·1	11·8	11·9	10·6	9·3	15·8	17·5	14·0	9·5	8·9	9·5	12·1
15—16 ...	10·9	10·9	11·4	10·7	9·5	15·4	17·5	13·7	8·8	8·8	9·2	11·4
16—17 ...	10·4	10·6	10·9	10·6	9·3	15·1	16·9	12·6	8·3	8·0	8·6	10·8
17—18 ...	8·8	9·4	9·8	9·8	9·1	14·7	15·5	11·6	7·1	6·8	7·0	8·8
18—19 ...	7·5	8·0	8·1	8·0	7·6	13·4	14·1	10·1	6·2	6·1	6·5	8·1
19—20 ...	8·3	9·0	8·8	7·6	7·1	12·4	13·4	9·9	6·3	6·0	7·1	8·4
20—21 ...	9·0	9·9	10·0	8·4	7·7	12·5	13·2	10·2	6·8	6·4	7·6	8·5
21—22 ...	9·3	10·6	10·1	8·4	8·5	12·6	12·9	10·4	7·3	6·5	7·3	8·8
22—23 ...	9·4	10·7	9·9	8·0	9·4	12·5	12·7	10·4	7·8	6·5	7·5	9.0
23—Mid. ...	9·4	10·3	9·2	7·7	10·0	12·1	12·4	10·4	8·0	6·9	7·5	8·9
Total ...	229·0	227·2	209·1	189·8	220·8	326·9	345·9	279·5	193·1	172·2	191·3	239·0

* The figures in this table are taken from the Memoirs of the Mysore Meteorological Department and are not comparable with the figures for Bangalore in Table VII.

Table VI.

Number of hours in each month the wind movement per hour exceeded 8·28 *miles* (A), *exceeded* 10·43 *miles* (B), *exceeded* 11·94 *miles* (C), *exceeded* 9·50 *miles* (D).

Month.	A	B	C	D
January ...	620	279	...	310
February ...	448	308	...	364
March ...	434	155	...	310
April ...	240	90	...	155
May ...	651	...	...	341
June ...	720	720	540	720
July ...	744	744	651	744
August ...	744	403	279	744
September ...	300	...	...	150
October ...	217	...	...	...
November ...	270	30	...	180
December ...	651	279	217	310
Total ...	6,039	3,008	1,687	4,328

constructed Table VI, similar to Table IV, in order to frame an estimate of what would be the work done by a similar aermotor in that locality. As the station is over 3,000 feet above the level of the sea, the density of the air is less and may be assumed to be 0·9 of that at sea level· As the work done by the wind is proportional to the mass multiplied by the cube of the velocity, a wind of 8 miles per hour at sea level will be as effective as one of 8·28 miles per hour at 3,000 feet elevation. The totals of the columns of Table V show, that a single 8 inch pump could be worked for 6,039 hours, and that two pumps could be worked for 3,008 hours, whilst three pumps could be worked for 1,687 hours, giving an increase to the amount

of water lifted of 50 per cent. for two pumps and a further increase of 28 per cent. for a third pump. If a 10 inch pump were used, it would work for 4,328 hours this number multiplied by 1·35, the ratio of the work done by two pumps in any given wind shows that the 10 inch pump would only lift 96·7 per cent. of the water lifted by an 8 inch pump, and an examination of the table shows that the greater part of this work would be done during three monsoon months and that during the rest of the year the 8 inch pump would be immensely more effective than a 10 inch pump. From these figures, it would appear that the wind movements in Bangalore are so much stronger than in Madras that the work which a 16ft. aermotor would do would be 60 per cent. greater. It would be interesting to extend this method of investigating the prospects of a wind-mill to a number of other places in India, but the hourly data are not available, and we must content ourselves with the daily returns published by the Meteorological Department. In Table VII the average daily wind velocity for each month in the year for some 28 stations fairly evenly distributed over India is given.

We have seen that the work done by the aermotor in Madras is proportional to the daily velocity of the wind, the equation being $X = 175(Y—53)$. Applying this equation to the figures giving the average daily velocity throughout the year we obtain the ratio given in the horizontal line $\left(\frac{M—53}{165\text{-}53}\right)$. This method is based upon the assumption that an 8 inch dump is in use. But in places of low

wind velocity it would be advisable to use a smaller pump, and in places of much higher wind velocity better results will be obtained with a larger pump. We have seen that the energy of the wind is proportional to the cube of the velocity and that the starting power of the wind is proportional to the square of the velocity, and it therefore seems not unreasonable to assume that the energy which can be derived from the wind may be taken as approximately equal to the square of the daily wind velocity. In Table VII. is given the ratio of the average wind velocity at each place to the average wind velocity in Madras $\left(\frac{M}{165}\right)$ and the squares of these numbers $\left(\frac{M}{165}\right)^2$. A comparison of the two sets of figures, $\frac{M-53}{165-53}$ and $\left(\frac{M}{165}\right)$ shows that only in places of extremely low or extremely high wind velocity there is any very material difference, and for this reason, I am inclined to think that the latter method of estimating the probable amount of work which can be obtained from a wind-mill in any locality is the more accurate.

It will be seen that at the great majority of stations the wind forces are so slight that we may unhesitatingly say that wind-mills are of no value. There remain, however, a certain number of stations where the conditions are favourable, and as these represent the wind conditions prevailing over an enormous tract of country, we arrive at this result: that though over the greater part of India including the whole of Northern India, the energy of the wind is of no practical value, yet there are many places in

—	Calcutta.	Cuttack.	Patna.	Allahabad.	Lucknow.	Meerut.	Lahore.	Peshawar.	Karachi.	Deesa.	Surat.	Belgaum.	Sholapur.	Poona.	Nagpur.	Jubbalpur.	Secunderabad.
January	62	34	48	81	58	49	43	64	239	208	125	249	184	134	93	53	90
February	80	53	70	100	79	68	54	82	249	211	130	237	174	149	123	60	97
March	118	84	82	110	96	66	70	91	281	209	156	272	190	190	133	72	105
April	169	122	106	117	106	60	77	104	329	228	192	320	213	234	161	84	113
May	172	122	115	149	103	64	79	116	407	325	305	424	255	342	228	108	173
June	142	96	101	166	101	64	88	113	423	397	374	556	316	360	240	127	217
July	122	77	86	151	94	57	80	107	415	351	377	647	336	386	243	120	249
August	115	62	77	134	72	48	69	93	397	278	326	517	296	327	191	110	203
September ..	98	202	70	128	67	46	50	73	356	200	221	385	245	274	147	82	150
October	67	46	46	66	46	31	39	60	235	161	122	241	193	139	102	50	96
November ..	62	41	36	49	34	29	32	51	193	181	142	267	199	138	95	43	88
December	61	31	41	60	41	37	33	61	217	194	120	299	182	133	83	43	81
Average daily wind movement, M ..	106	81	73	109	75	52	60	85	312	245	216	368	232	234	153	79	139
M—53.	53	28	20	56	21	0	7	32	259	192	160	313	179	181	100	26	86
$\frac{M\text{-}53^*}{165\text{-}53}$	0·47	0·25	0·18	0·50	0·18	0	0·05	0·29	2·32	1·71	1·43	2·80	1·60	1·62	0·89	0·23	0·77
$\left(\frac{M}{165}\right)$	0·64	0·49	0·443	0·662	0·452	0·314	0·36	0·512	1·876	1·485	1·307	2·425	1·405	1·415	0·928	0·48	0·839
$\frac{M^2}{(165)^2}$	0·41	0·24	0·19	0·44	0·20	0·10	0·13	0·26	3·52	2·20	1·72	5·90	1·97	2·00	0·86	0·23	0·70

—	Bombay.	Karwar.	Madura.	Salem.	Bangalore.	Mysore.	Trichinopoly.	Madras.	Masulipatam.	Bellary.	Gopalpur.
January	239	73	130	117	184	212	113	141	125	81	156
February	254	86	120	128	175	188	98	119	122	92	240
March	270	96	98	126	168	192	91	150	163	109	283
April	264	98	86	110	158	195	96	185	211	127	348
May	247	128	89	98	176	249	144	219	214	201	319
June	376	128	115	113	263	358	221	212	226	251	278
July	450	123	110	108	267	348	238	191	233	282	271
August	376	87	89	93	237	312	197	166	187	263	218
September ..	267	58	82	82	176	240	170	149	154	223	173
October	226	54	70	60	139	176	91	118	106	104	151
November ..	235	60	91	74	167	206	101	156	132	77	168
December	236	66	118	92	195	256	120	178	137	76	166
Average daily wind movement, M ..	287	88	100	100	192	244	140	165	167	157	231
M—53.	234	35	47	47	139	191	87	112	114	104	178
$\frac{M\text{-}53^*}{165\text{-}53}$	2·09	0·31	0·42	0·42	1·24	7·0	0·78	1	1·02	0·93	1·59
$\left(\frac{M}{165}\right)$	1·735	0·534	0·605	0·606	1·163	1·48	0·848	1	1·013	0·952	1·40
$\frac{M^2}{(165)^2}$	3·02	0·28	0·37	0·37	1·35	2·19	0·72	1	1·05	0·90	1·96

* 165 is the average daily wind movement in Madras where these experiments were made.

peninsular India where it should be profitable to make use of wind-mills for irrigation. Along the sea coast from Karachi to Bombay and from Diamond Harbour to Negapatam over a large tract of the Deccan, over the Mysore Plateau and probably in most of the hill stations, it will be found that wind-mills, if not absolutely ideal machines for lifting water, are by far the cheapest and most convenient of mechanical devices available. From the equation which has been obtained as the result of observations in Madras, it is easy to calculate the effective horse-power obtained from a wind-mill, and it will be seen that when the load is fixed, as it is by the size of the pump and the height over which the water is lifted, the actual horse-power of the wind-mill is not very large even when strong breezes are blowing. On the other hand, it must be remembered that a wind-wheel of from 12 to 20 ft. in diameter would be sufficiently large to extract all the water that can be obtained from the majority of wells sunk in this country, and that, as it is most effective in hot dry weather, it is a more convenient aid to irrigation than at first sight might be expected. We have seen that the amount of effective work which a wind-mill can do is increased 50 per cent. by the addition of a second pump, and as the cost of this addition is comparatively small compared with the cost of a wind-mill tower and one pump, I strongly recommend that all wind-mills erected for lifting water should be arranged so as to be able to drive two pumps during periods when the wind velocity is sufficiently high. Taken as a whole, the movements of the wind in India, though very much feebler than in

temperate climates, are fairly reliable and conveniently distributed, the maximum wind force usually occurring in the afternoon when the water in the well will probably be at its lowest level and the work of lifting it out therefore greatest. It may also be noted that, as a rule, during rainy weather the wind movements are feeble, but water for irrigation is not wanted then; whilst hot dry weather, when water is most wanted, is usually accompanied by strong winds. The actual results of irrigation with aer-motors should therefore be somewhat more favourable than calculations based on average returns indicate.

As the result of experience with the working of the aer-motor supplied by the Chicago Company, I am of opinion that these machines are not sufficiently strongly constructed for work in India. A good many minor breakages have occurred during the course of the experiments, but the most serious defects were due to the bad fitting of the valves in the pump chamber. The design seems to be excellent but the execution was bad and much trouble might have been obviated if the pivots on which the flap valves turn had been made larger and fitted into better designed sockets. A wind-engine and pump cannot be placed in inexperienced hands; they require carefully looking after, and slightest defect or damage should be remedied immediately it occurs. It will not pay to keep an experienced fitter to look after a single wind-mill, but the man could easily look after a dozen mills and where such colonies of wind-mills can be established they should prove remunerative investments.

A 16 feet aermotor mounted on a 40ft. tower and fitted with an 8 inch pump will cost, when erected over a well, about Rs. 1,500, and we may assume that the cost of maintaining the same in good order will be about Rs. 5 a month. Such investments should yield about 6 per cent. interest on the capital expended, or Rs. 7–8–0 a month. Ten per cent. for depreciation is perhaps an excessive amount to allow, but it will be well on the safe side if we do so. This comes to Rs. 12–8–0 a month, making the total cost of the wind-mill Rs. 25 a month. Now, this wind-mill will do as much work as at least 2 pairs of good cattle, and if fitted with two pumps, it will be equivalent to 3 pairs of cattle and the cost of lifting water with them will amount to from Rs. 45 to Rs. 67 a month, showing a margin in favour of the wind-mill of from Rs. 20 to Rs. 40 a month. This is the result that can be obtained in Madras, but there are thousands of square miles of country in India where much more favourable results can be obtained, and I therefore conclude this brief account of my observations on a wind-mill in Madras with the statement that there is a wide field in India open for the profitable employment of wind-mills in lifting water for irrigation.

WIND-MILL IRRIGATION IN AMERICA.*

THERE is a generally prevalent idea that in the United Sates wind-mills are very largely used for lifting water from wells for irrigation, and during a recent visit to that country I availed myself of such opportunities as came in my way to find out exactly what a practical race like the American farmers have been able to get out of the wind. Not very long ago a typical American wind-mill was lent to me by the Chicago Air Motor Company and I kept it under observation for a year in the compound of the School of Arts, Madras. At the end of that time I felt justified in expressing the opinion that "there is a wide field in India open for the profitable employment of wind-mills in lifting water for irrigation," but that "the air motor supplied by the Chicago Company was not sufficiently strongly constructed for work in India." In the United States I saw many thousands of wind-mills, but very few of them were used for irrigation. They are nearly all employed either to drive light agricultural machinery, to raise water for domestic purposes, for watering stock, or for a small garden round the house. The water is raised from a well and stored in a tank from 10 to 20ft. above the ground, the tower of the wind-mill being usually made strong enough to carry the tank. In most instances the supply of water required is not very large, and

* *The Madras Mail*, 1905.

as soon as the tank is filled, the wheel is thrown out of the wind. And even when a good breeze is blowing it is not uncommon to see the majority of the wind-mills in a village or small town standing idle. Experience has shown that the cheap wind-mills of America rapidly wear out, and so they are carefully looked after and not allowed to run unnecessarily.

Most of the wind-mills are of small size, 8ft. and 10ft. diameters being most numerous. I visited the works of the largest firm of wind-mill makers in the world, and in conversation with the Manager he claimed that his firm had sold 400,000 mills in the last few years and that they were exported to all parts of the world. Judging from the size of the works and the very complete mechanical equipment, there seemed to be nothing improbable about the statement of output. But I was surprised to hear that they themselves did not consider their wind-mills strong enough for regular irrigation work. To sell large numbers of mills it was essential that they should be cheap, and to keep the cost of construction down to the lowest possible limit economy of material is practised to such an extent that the factor of safety is reduced to a minimum and there is very little margin for wear and tear. In the design lightness is considered of extreme importance so as to save expenditure on materials and transport, and methods of construction are adopted not because they are the best that can be devised but because they require little skilled labour in the fitting of the parts and the erection of the whole. The result is not satisfactory from an irrigation point of view, and this is borne out by the fact that wind-mills are not

largely used in the United States for irrigation, except in certain areas where the local conditions are unusually favourable.

Progress is so rapid in the States that it is difficult to get accurate statistical information, and even when such information is obtained it soon gets out of date and possesses little practical value. In consequence the following figures and statements taken from the sixth volume of the U. S. Census returns, which relate to the year 1899, cannot be accepted as accurately representing the state of affairs at the present time, for there is not the least doubt that there have been considerable developments since then. Nevertheless, they help to substantiate the conclusion I have come to that no very great use is being made of the wind to lift water for irrigation. In 1899 there were about 170,000 acres of irrigation under wells, of which over 152,000 acres were in the State of California. And as to the motive power employed for raising the water it is remarked :— "Wind-mills are not generally employed, even the smaller plants being operated by steam, gas or electricity." In the States of Kansas and Nebraska wind-mill irrigation is generally regarded as having reached its highest developments ; yet it does not amount to anything material, since in 1899 there were only 1,909 acres irrigated by 599 wells in Kansas, and in Nebraska only 843 acres of such irrigation. Even if these figures could to-day be multiplied ten times, which is doubtful, they would not represent anything very important.

Of the neighbourhood of Garden City, Kansas, Mr. E. C. Murphy, of the U. S. Geological Survey, writes :—

"Perhaps nowhere in the United States is irrigation from wells by the use of wind-mills carried to the same extent as there, where may be found hundreds of wind-mill pumping plants furnishing water to irrigate for 1 to 15 acres each." During the irrigation season, which extends from April to September, the average daily wind velocity is 295 miles, and the water supply is contained in beds of sand and gravel situated at depths below the surface varying from 8 to 40 ft. The wells are usually 3 to 4 ft. square and sunk as far as can be conveniently done into the water-bearing beds. They are lined with wood, and from the bottom perforated galvanised iron tubes from 6 to 12 inches in diameter are put down so as to increase the area of percolation into the well. Nearly all the pumps are of the reciprocating piston type and are, as a rule, 6, 8 or 10 inches in diameter. They are well designed, and the valves can easily be withdrawn for examination and repair. The working efficiency on lifts of over 20 feet is usually 75 per cent. or more. From the results obtained in Madras with the aermotor it would appear that under such conditions a 16ft. aermotor should be capable of lifting an average of 42,000 gallons per day from a depth of 25ft. or enough water to irrigate 20 acres of land. The conditions, therefore, are very favourable for the employment of wind-mills, and it is not surprising that they have been made use of. The only wonder is that more of them are not at work.

Undoubtedly the main reason is the unsatisfactory character of the ordinary wind-mill, which is so lightly built that it can only be allowed to work in moderate winds and is, therefore, arranged to gradually move out

of the wind as its velocity increases. This is a serious defect, as the power of a wind-mill is proportionate not to the velocity of the wind but to something more than the square of the wind velocity. Obviously the wind-mill should be so constructed that its efficiency as a motor remains nearly constant through a wide range of wind velocities. In order that this may be the case the initial load should be extremely small, so that the mill will start in a very light wind. As the velocity increases the load should increase in nearly the same ratio, and the work done will then be proportionate to the square of the wind velocity. To attain this result in a pumping-mill is a very difficult matter and has never yet been satisfactorily accomplished. It can only be done by using a pump of variable stroke, and introducing some simple device for making the length of the stroke proportionate to the velocity of the wind. Any arrangement which is not automatic is of very little value, except, perhaps, the device of driving through a rocking shaft two or more pumps provided with simple means for throwing them in or out of gear. With light winds one pump can be used, with stronger winds two and in some places it might be profitable to employ a third pump. In America this method of working would probably be of little value; as it would entail periodic visits of a man to adjust the load to the wind, and this would be costly. But in India it would be quite practicable, as labour here is very cheap and the diurnal variations in the wind velocity are very regular.

Our limited experience in India and the results of my enquiries in America are in complete accord. The cheap

American wind-mill outfit is not suited for irrigation work, and a stronger, stiffer design is absolutely necessary if it is to find favour in this country. The manufacturers should aim at producing a wind engine with a wheel about 16ft. in diameter, mounted on a tower 40ft. high, which is sufficient for most places. The wheel should be geared down to the pump shaft in the ratio of 3 to 1, and the pump should be from 10 to 20 inches in diameter, depending on the lift, and fitted with mechanism yet to be invented, which would enable the length of the stroke to be varied automtically with the velocity of the wind. The design should provide for utilising the full force of the wind up to 30 miles per hour, but beyond this velocity the governor should come into play and as quickly as possible throw the wheel out of the wind. For such a wind-engine and pump erected over a well it would be practicable to pay from Rs. 1,500 to Rs. 2,000, or from £100 to £130. The pump is a comparatively simple matter, but it requires careful design and must be well made so that it will be but little likely to get out of order. Bucket leathers are probably the source of most trouble, but I am informed chrome leather makes a much more durable material for such fittings than the ordinary bark-tanned leather which is now universally employed. If this be so, it is an important improvement and should be adopted. In any case, it should be possible to remove all the valves from the pump and replace them with certainty even when the pump barrel is deeply submerged in the water. The wind engine pump invariably does all the work on the up-stroke, and to obtain a fairly uniform resistance to the turning moment of the

crank shaft, the weight of the pump-rod and bucket should be more than counterbalanced, so that on the down-stroke work is done which is restored during the up-stroke. This can be effected by floating the pump rod in the delivery tube or by the use of counterbalance weights. By suitably proportioning the section of the pump rod to the section of the delivery pipe, a very satisfactory distribution of the work can be obtained with a fairly uniform delivery of the water.

For irrigation it is absolutely necessary that the pump should deliver the water into a storage reservoir which can be most cheaply made with earthen banks, provided these can be made water-tight. The banks should be about 15ft. wide at the base, 2ft. wide at the top and 4ft. 6in. high. The reservoir should be square in plan with sides not less than 60 ft. long on the inside of the banks at their base, and it should be filled to a depth of 3 ft., so as to supply water for about 2 acres at a time. The reservoir should be provided with a small outlet to the well at the 3ft. level to prevent overfilling, and with a fairly large masonry sluice so that its contents may be discharged rapidly, as otherwise there will be a great waste of water if it is run on to the land in a small stream. In America, and especially in California, much greater attention is paid to this point than is usual in India, except in gardens where masonry conduits are in common use. If the practice were extended to fields under well irrigation, the greater duty obtained from the water would amply repay the extra cost.

To conclude, wind-mills have not yet had a fair trial in India. Some have been set up in Districts where there

was insufficient wind; and all have been too lightly built for the heavy work they have been called upon to perform where the wind was strong enough. In America better results have been obtained; but even there the present cheap type of mill is recognised as unsuitable, and manufacturers are considering whether the demand for an irrigation mill is sufficient to make it worth their while to meet it.

WATER-LIFTS.*

:o:

IN 1895 the Government of Madras appointed a special Committee to report on the merits of certain machines for raising water from wells, to which their attention had been drawn by the inventors. Of this Committee I was a member, and our reports were officially published as Bulletin No. 32 of the Agricultural Branch of the Department of Land Records and Agriculture. Our enquiries revealed the paucity of accurate scientific data regarding the working and efficiency of the ordinary water-lifts of the country, and disclosed the fact that until such data were collected and carefully studied, it was hardly likely that any material improvement could be effected in the modes of lifting water from wells. Recognising the importance of well irrigation in India, I have, during the past twelve months, endeavoured to supply this deficiency, and, with the assistance of the Board of Revenue, represented by Mr. C. Benson, whose cordial co-operation I have to acknowledge, experiments on a number of typical water-lifts have been made, and results obtained which, it is hoped, will show the direction in which improvement is most likely to be obtained, and the available margin which exists for inventors to work upon.

In the Statistical Atlas of India, the total irrigated area is stated to be 28,334,000 acres, of which 10,140,000

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* Originally published as Bulletin No. 35 of the Agricultural Branch of the Department of Land Records and Agriculture, Madras 1897.

acres, or more than one-third are entirely dependent upon water drawn from wells. In the Madras Presidency, excluding feudatory and tributary States and Zemindari lands, the area under irrigation amounted to 5,803,937 acres in 1894-95, and of this area 1,084,060 acres were supplied with water from 427,539 wells whilst the lands under other systems of irrigation derived a supplementary supply from 139,136 wells. These figures will serve to indicate the magnitude of the interests involved in irrigation from wells, but possibly a clearer idea may be gained from the calculations given below, which, though based on admittedly approximate data, show in greater detail what well irrigation in India means. In Madras, the average area under each well is 2½ acres, but in other Provinces it is larger, and for the whole of India probably averages 4 acres per well, so that the total number of wells must be about two-and-a-half million. The cost of constructing 13,337 wells is given as Rs. 16,88,753 in certain returns furnished by the Board of Revenue, Madras, or an average of Rs. 126 each, and as in many places the wells are much deeper than they are in Madras, we may assume, without fear of exaggerating, that the average value of a well in India is Rs. 150, and that, therefore, the total capital invested in wells amounts to the very large sum of 37½ crores of rupees.

Taking the duty of water for garden or well cultivation at 250 acres per cubic foot per second, the quantity required for over 10 million acres would be 40,000 cubic feet per second, and if we assume that the average depth from which the water is lifted is 30 feet, the work which has to be done amounts to 136,000 horse-power. Cattle, however,

do not work more than 8 hours a day, and the efficiency of native water-lifts certainly does not exceed 50 per cent., so that the aggregate horse-power derived from cattle in India and employed in lifting water amounts to 816,000. Assuming that throughout the cultivation season there is an average of two bullocks at work every day at each well, there would be about 5 million cattle so employed, and each would be doing work equal to one-sixth of one horse-power, a result which is undoubtedly not very far from the truth.

The average quantity of water yielded by each well is, upon the above assumptions, 8,640 gallons per day, a volume so small as to entirely preclude the use of any, but the simplest possible appliances for lifting the water to the surface. Steam-pumping machinery is utterly beyond the means of the ryots, and the force of the wind is too uncertain, and, in general in India, it is too weak to be profitably utilized by wind-mills even of the most modern type. Animals are, therefore, the only source of power available, and water-lifts in the future* must continue to be, as they always have been, worked by cattle. Moreover, the Indian agricultural population are so singularly devoid of even the most rudimentary mechanical skill that it is absolutely necessary that machines, intended for their use, should be designed to work without complicated gearing of any kind. As will be seen in the sequel, native methods of lifting water comply with these conditions and possess at the same time, under favourable circumstances, a fairly high effici-

* It should be remembered that this report was written in 1896 before oil engines had become the simple, practical motors they are to-day.

ency which renders the task of endeavouring to improve upon what is already in use exceedingly difficult.

The enormous amount of energy which is expended on raising water from wells has naturally attracted much attention, and from time to time, in different parts of India, attempts have been made to introduce what were considered improved appliances, but so far no great amount of success has been achieved, and the opinion is now generally held that little or nothing can be done. Of the special reports, which have been prepared on the subject, two at least may be cited. The first is a volume published in 1883 by the Department of Agriculture and Commerce in the North-West Provinces and Oudh, of which the most important section is a report by Captain Clibborn, B.Sc., an Executive Engineer, who was placed on special duty in connection with the matter, and who, after collecting a vast amount of information regarding existing practices in the North-West Provinces and carrying out a very large number of experiments on the performances of the various types of water-lift in use, expressed in unequivocal terms the opinion the Government could do little or nothing to improve or extend well irrigation in the Provinces. The second report was prepared in Bombay by an Executive Engineer, Mr. F. D. Campbell, after spending three months on special duty, and as the final result of his enquiries he formulated the opinion that nothing can be done to introduce "new or cheaper systems of well construction or of lifts than those which the ryot is already familiar with."

In recent years, in Madras especially, these conclusions have not been accepted by a certain number of practical

men who have devoted much time and ingenuity to the production of improved water-lifts and their efforts have at any rate, resulted in drawing public attention once more to the water-lift question. The trials conducted by the "Water-lift Committee" showed the necessity of studying the problem scientifically and of taking into account a factor which had hitherto been entirely neglected, *viz.*, the mode of applying animal power. Notwithstanding the number of experiments, the results of which have been published, it was found impossible to compare the performances of the new machines with those obtained from native water-lifts owing to the insufficiency of the data recorded, and though it did not fall within the scope of the reference to the Committee to obtain the necessary figures, it was considered highly desirable that a fresh set of experiments should be undertaken, so as to render it possible to make fairly exact comparative statements on the merits of totally different forms of water-lift, after trials which should be neither tedious nor difficult to carry out.

The fact that animal power is employed in all forms of water-lift renders it exceedingly difficult to make comparative trials of machines, some worked by one class of bullock in a certain manner and others worked by another, and possibly inferior, class of cattle in a totally different way. Not only have we to take account of the mechanical efficiency of the machine, but also the method by which the animal is made to work must be considered, since the amount of useful energy which can be obtained from an animal depends very largely upon the way in which the muscular efforts are made. The work done by an animal in

motion may be conveniently divided into two parts, which we may term internal work and external work, respectively. The latter only is available for useful employment, and, as the sum of the two is probably a constant quantity, it is evident that the more we can reduce the expenditure of energy on internal work, the greater will be the amount available externally. For instance, a bullock walking along a level road expends the whole of his strength on internal work, which simply results in the transportation of his body from one place to another, but if we yoke him to a cart, the work which he does is partly internal and used in his own movement and partly external and employed in drawing the cart.

What ratio the internal bears to the external work cannot be accurately determined, but there are some facts which enable us to form an approximate estimate. A bullock doing no work can be made to march only a certain number of miles in a day without experiencing undue fatigue. The addition of a moderate amount of external work diminishes the distance which can be travelled, but only to such an extent as to indicate, that of the total muscular exertion the greater part is expended internally. On a horizontal road and walking at his natural gait, a bullock can exert a draught of one-tenth of his weight for a period of 8 or 9 hours a day. That is to say, he can do work in drawing a cart or a plough along the level equivalent to what he would have to do if he walked up a gradient of 1 in 10. No animal is strong enough to exert a continuous draught equal to one-fifth to his weight, for any length of time, without injury, and a draught

equal to one-third of the weight can only be exerted spasmodically and for very short periods, yet a man or a bullock when in training can, with comparative ease, walk up a gradient of 1 in 3 and continue to do so for a very long time if the pace be not too great, and if the surface walked on be suitably prepared. It is evident, therefore, that when an animal raises his own weight against the action of gravity, the external work, represented by the potential energy stored in the animal's body, bears a greater proportion to the internal work, which is uselessly expended, than is the case when the external work is due to a pull exerted through a certain distance. For instance, a bullock will walk, along the level, two miles in one hour against a draught equal to one-tenth of his weight and will do, what we may term, a unit of work, equal to raising his own weight one-fifth of a mile; up a gradient of 1 in 3 he would probably walk $1\frac{1}{2}$ miles in one hour and raise his own weight vertically through half a mile, doing $2\frac{1}{2}$ times as much work. Even if he could only do one mile per hour up the slope, the potential energy stored in his body would still be $1\frac{2}{3}$ times as great as if he had been employed in drawing a weight up a vertical shaft by a rope passing over a pulley.

Practically we may assume, then, that an animal, with the same ultimate expenditure of energy, can do twice as much work in raising his own weight against the action of gravity as he can in the only other way it is feasible to employ him. This fact has long been vaguely known, but has not been made much use of, owing to the difficulty which has been experienced

in designing suitable mechanism to embody the idea, without producing a machine both cumbrous and costly. This the Hindu cultivator has recognised, and with more than characteristic ingenuity has devised a compromise between the two methods of working in an exceedingly simple manner, as exemplified in the ordinary country mhote, in which he partially obtains the advantage of the bullocks' weight, by making them run down a steep incline when drawing from the well the bucket full of water, whilst in the picottah, which he himself has to work, the principle has been fully carried out with the result that it is capable of but little improvement, except in the direction of making it a less hazardous machine to work.

A pair of bullocks is a vague term; they may be worth Rs. 40 or Rs. 250, and one pair may easily be capable of doing more than twice as much work as another; yet in previous accounts of experiments on water lifts no more definite information than this has been forthcoming as to the power employed. Dealing with water-works, engineers are accustomed to state the results of the trial of a pump something in this way. The engine driving the pump indicated 'X' horse-power and 'Y' gallons of water were lifted against a head of 'Z' feet in a certain time. Unfortunately, we cannot measure the work done by cattle in absolutely definite units as in the case of the steam-engine, but it is a generally accepted fact that the strength of well conditioned animals of the same species is roughly proportional to their weight, and it would therefore have added enormously to the value of former

experiments on water-lifts if the weight of the cattle used had been ascertained.

The value of a water-lift depends partly upon its mechanical efficiency and partly upon the efficiency of the method by which the strength of the animal is utilized when working it. The mechanical efficiency can usually be determined without difficulty, but it does not seem possible to express in numerical terms the ratio which the internal work of the animal bears to that done externally. For practical purposes, however, a constant involving both terms is what is required, and this can be obtained without difficulty. The amount of useful work done in one hour, expressed in foot-pounds, divided by the weight of the animal in pounds, represents the vertical height in feet, to which, by the expenditure of a similar amount of work, the animal's body would be raised. The magnitude of this constant, which may be conveniently termed the *co-efficient of utility*, offers a a simple means of stating concisely the value of a water-lift as a machine for getting work done by the agency of animal power. The determination of this constant has therefore been one of the most important objects of the trials recorded in this paper.

In trials of water-lifts, there is a liability to a serious error in estimating the outturn of work from the fact that animals can be made to work at a much faster rate for a short time than they can sustain for a prolonged period. With experience it is possible to judge if animals are seriously over-driven; or, if experiments can

be extended over a sufficient number of hours, over-driving at the start will be revealed by a gradual slackening of the rate of doing work. In the present series of trials, every effort was made to secure that the animals should be driven at their normal speed, and it is believed with success, but as in most cases there was only a limited time for experiments, the rate of working was checked against the animal's weight. Agricultural authorities, in calculating the rations for draught cattle, assume the working day to be eight hours and the rate of doing external work to be 0·25 foot-tons per ℔. of weight per hour. This is considered to be the maximum amount of work which can be obtained, without affecting the health of cattle, and an increase, either in the rate or in the total quantity of work done, soon produces deterioration and sickness. There appear to be no data available as to the amount of work which can be got from cattle in India, but it is probably rather less than in temperate climates, and the value of the figures obtained in these trials lies chiefly in the fact that they enable us to judge at what rate the cattle were worked. It will, of course, be understood that the more the weight of the animal was used, the greater should be the rate at which work can be done, and that the highest rate should be obtained for lifts in which the animal exerts no draught, but simply raises himself up an inclined plane till it overbalances the resistance to be overcome, and useful work is done by the steady descent of the animal under the action of gravity. In this case the rate of working ought to be about 0·5 foot-tons per lb. of weight per hour.

More than 50 years ago a Mr. F. W. Simms communicated to the Institution of Civil Engineers the results of some observations which he had made on the amount of work which horses can do at various rates of working. The average weight of the horses was 1,176 lbs. and the results are concisely stated in Table I.

TABLE I.

Working day in hours.	Foot-pounds of work done per horse per minute.	Relative amount of work done in a day.
8	23,412	100
6	24,360	78
4½	27,056	65
3	32,943	53

In Captain Clibborn's report on well irrigation in the North-West Provinces are given the results of an extensive series of experiments made on the quantity of water raised from wells of different depths by various methods, from which it appears that the work done by cattle varies very greatly, depending on conditions not explicitly stated, but of which the most important, evidently were, the size and strength of the animals, the depth of the wells and the type of water-lift employed. In Table II, a few of the results have been extracted and the capacity of the bucket is given to serve as an indication of the size and strength of the cattle as it is evident that only big, powerful beasts could exert a draught of over 500 lbs.

TABLE II.

Depth to water-surface in feet.	Capacity of bucket in gallons.	Work done per head per minute in foot-pounds assuming efficiency of lift to be 50 per cent.
57	16·2	9,384
37	28·7	7,426
17	25·2	3,136
12	21·8	2,490
53	47·7	11,678

In the same report, it is stated that with men, working the dhenkli, the useful effect obtained averaged 1,120 foot-pounds per minute, which would mean that, after due allowance had been made for the imperfect efficiency of the machine, the men were doing about 12 foot-pounds of work per lb. of weight per minute.

In Table III the results of the experiments made in Madras are collected together, and sufficient details given, to show that the variations in the output of work are mainly due to the different methods of making use of animal power, and it will be seen that they occur exactly as one would be led to expect from the conclusions arrived at when discussing this point.

The figures obtained with picottahs worked by men are very striking, especially when it is borne in mind that the work of one man is almost entirely confined to guiding the bucket rod and emptying the bucket, and that only the two men perched on the see-saw lever are employed in

TABLE III.

Name of lift.	Nature of work.	Weight of cattle.	No.	Footpounds of work done per minute per animal.	Footpounds of work done per minute per lb. weight.
		lb.			
Stoney's double mhote.	Draught in a circle, intermittent.	1,146	1	12,060	10·52
		1,438	2	5,410	7·52
		1,146	1	10,308	9·00
Single mhote by Subba Row.	Draught down an inclined plane.	1,348	2	12,180	18·07
See-saw water-lift.	Walking up an inclined plane and reversing.	700	1	9,625	13·75
Sultan Mohideen.	Draught in a straight line and reversing.	1,596	2	6,425	8·05
Andrew's Persian wheel.	Draught in a circle continuous.	985	2	6,695	13·58
Single mhote, Bellary.	Draught down an inclined plane.	2,688	4	12,225	18·20
		2,058	4	5,762	11·21
Single mhote, Coimbatore.		774	2	6,180	15·99
Do.		1,320	2	9,430	14·29

lifting the water. Compared with the dhenkli, in which the water is raised by pulling with the arms at the end of a balanced lever, the resultant effect is more than twice as great.

With the exception of the Persian wheel and modifications such as the chain pump, all the water-lifts used on

TABLE IV.

Name of lift.	Nature of work.	No. of men.	Weight of men in lbs.	Foot-pounds of work done per man per minute.	Foot-pounds of work done per minute per lb. weight.
Picottah ...	Walking on see-saw lever.	3	308	2,610	25·4
		3	331	2,737	24·81

wells in India consist essentially of a combination of two distinct parts. They are (1) a bucket or buckets for holding the water and (2) an arrangement of some kind by which animal power can be conveniently applied to do the work of raising the full buckets from the well. The buckets are usually made either of leather or iron and may be divided into three classes: (1) a simple leather bag such as is used very largely in Northern India, which requires a man to be specially stationed at the mouth of the well to tilt it over to discharge its contents, or a plain iron bucket or dish of the type generally used with picottahs; (2) cylindrical iron buckets suspended from stirrups so as to automatically tilt over and fill when lowered into the water, but which require a tilting bar or some equivalent device to empty them; (3) leather or iron buckets fitted with valves. The most ingenious and simple of all

these is the common leather mhote, used all over the South of India which consists of a roughly hemispherical leathern bag, suspended from an iron ring and fitted at the bottom with a leather trunk or discharge pipe, the end of which is held by a separate rope above the level of the water in the bag, whilst the latter is being drawn up the well. The ropes are so adjusted that on reaching the top of the well the bag continues to rise whilst the trunk is drawn inwards, with the result that the water is rapidly and completely discharged. Of iron buckets fitted with valves various forms have been proposed, but the only one, that has so far obtained any vogue, is that used with the Sultan water-lift; it is cylindrical in form with a flat bottom, in which is placed a large flap valve opening upwards when the bucket enters the water, and kept closed by the pressure of the water on it during the ascent, till at the top the valve is raised by a system of levers, which are depressed by coming into contact with a fixed stop.

Of possible mechanical arrangements for applying animal power to raise the buckets an indefinite number could be devised, but, owing to the necessity for extreme simplicity and cheapness, there are few that can be considered of any practical importance. A single bucket, suspended by a rope passing over a pulley, fixed over the mouth of the well, and attached directly to a bullock's yoke is the simplest and almost universal way of working throughout India and when the details are arranged to suit the local conditions the single mhote, as it is called, can hardly be surpassed by any more elaborate method. When two buckets are in use they can be made to balance one another

by carrying the ropes round the drum of a gin or whim in opposite directions, so that when one ascends, the other descends, as exemplified in the ordinary double mhote. Reversing gear, to obviate the necessity of making the cattle turn round after each bucket is emptied, could easily be provided, but would seldom be used as it would render the whim too costly to construct. By the use of bevil wheels, the whim can easily be adapted to work Persian wheels and allied types of water-lift, which continuously revolve in the same direction. In the Sultan water-lift, the buckets are balanced by being suspended at the ends of a rope which is carried over a series of pulleys so arranged that a pair of bullocks can be yoked directly to the rope, which when pulled in one direction raises one bucket and when pulled in the reverse direction raises the other bucket. Lastly, there is the picottah with its balanced lever worked by men and the various modifications of it which have been proposed to render it suitable for employment with cattle.

Experiments have been carried out either by the Water-Lift committee or by Mr. Benson and myself since the submission of its report on all the types of water-lift enumerated above, but no attempt was made, nor was it deemed desirable, to experiment with pumps and other devices of modern mechanical engineering, as the investigation has been purposely confined to appliances used by ryots or likely to come within the scope of their very restricted resources.

Methods of measurement employed in the experiments:— All weights were determined and draughts measured with

a Salter's Spring Balance, recording to 500 ℔s. and indicating differences of half a pound, which, previous to the commencement of the experiments, was tested with dead weights. Measurements of draught and friction were made by inserting the spring balance which was used as a dynamometer in the line of action of the forces exerted by the bullocks and employing a number of coolies to work the lifts in their place. In machines like water-lifts which of necessity are somewhat roughly constructed, no great amount of labour is expended on fitting the moving parts together; and, in consequence, the working is not perfectly smooth and the friction varies considerably in a single operation of the machine. The measurement of draught is, therefore, not very easy and the results are, in every case, the mean values obtained from a large number of observations. In most instances the average quantity of water brought up by a bucket was measured by passing the water into a tank of known dimensions and counting the number of buckets required to raise the water-level to an amount which was carefully measured. The tank was always filled and emptied several times and the mean result was undoubtedly very accurate. In one or two instances no tank could be procured and the water was measured in a rectangular trough dug in the ground, and, with proper precautions taken to ascertain the loss due to percolation, it was found a satisfactory method. The cattle employed during the trials were in every instance weighed on platform weighing machines, the wells chosen for the experiments being specially selected with reference to the facilities for weighing in the neighbourhood.

Stoney's water-lift :—The principle feature in this lift is the employment of buckets of wrought iron suspended in a stirrup by two adjustable pivots attached to the bucket very slightly above the centre of gravity of the bucket when full of water. The mouth of the bucket is inclined and the lower ends of the stirrup are turned outwards and formed into rings sliding on steal wires which are suspended in the well from screwed eyebolts attached to the framing above. The wires are fastened by some convenient means to the bottom of the well and act as guides to the bucket ascending and descending and prevent it from either turning round or swaying to and fro, and thus striking the sides of the well or the second bucket. On the bucket being lowered into the water it turns horizontal and as it sinks fills with water. On being drawn up it assumes a vertical position and rises steadily till the discharging level is reached, when the upper side of the inclined mouth comes into contact with an iron bar fixed across the framing of the lift and the stirrup continuing its upward motion causes the bucket to revolve about the point of contact of the bucket with the iron rod, and thus discharges its content into the delivery trough. The lift was worked by carrying the ropes which hold the buckets over guide pulleys to a whim. Two buckets are attached and the ropes arranged so that as one bucket ascended the other descended, and the dead weight of the buckets was balanced. The whim consisted of a drum built of wood and was carried by an iron spindle on the top of a post firmly built into the ground. The bullocks worked at the end of an arm which was 3·85 times the radius of

the drum. The whim was worked alternately in one direction and the other, the cattle being made to turn round whilst the bucket was discharging its contents.

Improved single mhote of M. R. Ry Subba Rao:—

The improvement on the ordinary single mhote is effected by attaching a rope to the draught rope and carrying it on to the large drum of a kind of windlass erected at the end of the inclined plane and at a considerable height above the level of the end of the run. Ropes wound round two smaller drums, one on each side of the large drum, carry weights which balance the weight of the empty bucket so that at the end of a lift as soon as the bucket is emptied the draught rope automatically rises in the air and the bullocks are able to turn round and walk up the inclined plane in a natural easy manner instead of being forced backwards as with the common plan. The improvement effected is undoubtedly very considerable, as not only is the weight of the empty bucket balanced but the animals are also spared the cramped and unnatural backward walk up a steep incline which probably tires them more than their exertions in drawing the bucket out of the well.

See-saw water-lift of M. R. Ry Subba Rao :—In this form of water-lift the bullock is made to walk along a platform supported on a roller and by his weight it is caused to oscillate up and down. Two ropes are attached to one end of the platform and wound round two small drums forming part of a windlass, round the large drum of which a rope working an ordinary single mhote is passed. The platform is not supported in the middle but

at some distance therefrom, so that the working end of the platform greatly preponderates and the bullock has to walk to the free end of the platform to tilt the longer segment up and lower the bucket into the well. To diminish the shock, when the free end falls and the bucket is lowered into the water, iron rails are fastened underneath the platform by a short chain so that just before this end of the platform reaches its lowest position the rails rest on the ground and their weight ceases to act and thereby the platform comes to rest more gently than would be the case if the velocity of descent continued to accelerate to the very end.

Single mhotes.—Experiments with single mhotes were made at Palladam in the Coimbatore District, where they are worked with a single pair of cattle, which are trained to walk backwards up the ramp. The slope of the run is therefore limited to 1 in 5 which is about the maximum that the cattle can be backed up. At Bellary, where experiments were also made, the lift is usually worked with two pairs of cattle, each pair drawing up alternate buckets of water. At the end of the run, the rope and bucket are detached from the yoke and fall back into the well, assisting the driver who grasps the end of the rope, to return up the steep slope, whilst the bullocks turn round and walk up a side path, which is not nearly so steep as the ramp. When the bucket is again in the water, the second pair of bullocks are hitched on to the rope and draw up another bucket full of water whilst the first pair are leisurely walking up the incline, so as to be ready at the top by the time the driver returns with the rope. With this system

of working, it is possible to make the slope of the ramps very steep and the gradient is usually from 1 in $2\frac{1}{2}$ to 1 in 3. The weight of the bullocks is therefore more effectively utilized, and a much larger bucket can be used than in the Coimbatore District.

The modification of the single mhote invented by M. R. Ry. Subba Row enables most of the advantages of this system of working to be obtained with one pair of bullocks. Moreover, the bucket is balanced, but it is doubtful if this contributes any real increase to the efficiency of the lift, as the friction of the extra pulleys absorbs power and more work is thrown on the driver since the unbalanced bucket materially assists the driver in climbing the steep ramp.

The Persian wheel.—Mr. Andrew, a missionary of the Free Church of Scotland stationed at Chingleput, has erected a form of Persian wheel at the Christian Pariah Settlement of Melrosapuram which he invited me to test. It is built on a framing of old railway rails over a circular well about 24 feet 6 inches in diameter. The rotating drum was 6 feet in diameter and 3 feet 8 inches wide and carried a double chain of sheet iron buckets each holding 1·80 gallons. The axis was prolonged on one side and driven through a pair of bevil wheels by a whim of the ordinary type. Each bucket was provided with a leather flap valve to permit of the escape of air from the descending buckets as they entered the water. The design was carefully worked out and the water-lift was very strongly made, so that it worked very satisfactorily during the trial.

The Sultan water-lift:—This is a direct draught water-lift with balanced buckets, the detail of which have been very ingeniously worked out, but the paramount necessity for keeping the cost down has resulted in the use of an unsatisfactory system of construction, which prevents to some extent the full advantages of the design being realized. The buckets are fitted with valves, as already described, which when new are water-tight; but in ordinary daily use they soon get slightly out of order and then leak considerably. Trials were made on one which had been put up in a garden in Tondiarpett to the north of Madras by M.R.Ry. Sundaram Sastri and on one, which has recently been erected near Bellary, in a garden belonging to M.R.Ry. Aerada Rudrappa. The only important difference between the two lifts was that the former was fitted with hemp ropes and the latter with wire ropes. I should have preferred to have tested a water-lift under the management of the makers but, though I offered to do so, they declined to place one at my disposal.

In the following tabular statement (Table V) are given the results of the trials which I have made. None of the trials were very prolonged, but they were all made under normal working conditions, and the results are only so much better than would ordinarily be obtained in practice* as may be fairly ascribed to the fact that care was taken to have the water-lifts in good working order and the

* Subsequent experience of the working of native water-lifts leads me to think that the results obtained during our trials were at least twice as good as those usually obtained by the cultivators under the normal working conditions.

TABLE

Name of water-lift.	Date of trial.	Mean lift in feet.	Duration of trial in minutes.	Gallons raised per hour.	Foot-pounds of useful work done.
Double mhote, Saidapet.	18 July 1895	22·125	180	1,867	413,000
Stoney's improved double mhote.	16 July 1895	22·625	90	2,594	586,900
	16 July 1895	23·24	166	2,489	575,500
	17 July 1895	22·87	111	2,391	546,900
Stoney's improved double mhote.	9 July 1896	23·5	427	2,097	492,795
	11 July 1896	23·5	422	2,220	521,700
Subba Row's improved single mhote.	18 July 1895	23·00	60	2,178	500,940
Subba Row's sea-saw lift.	23 July 1895	18·1	45	1,903	342,540
Sultan water-lift.	30 July 1895	21·0	60	2,570	539,857
Andrew's Persian wheel.	27 Feb. 1896	10·895	25	3,661	398,890
	27 Feb. 1896	12·375	120	3,204	395,500
Single mhote, Palladam.	30 May 1896	38·75	63	1,345	539,700
	31 May 1896	38·75	180	1,523	...
	31 May 1896	32·25	120	1,110	358,039
Single mhote, Bellary.	22 June 1896	35·50	102	3,766	1,337,000
	25 June 1896	35·50	240	3,347	...
	23 June 1896	13·0	165	3,511	456,400
Picottah.	10 June 1895	19·25	16	1,952	375,810
	20 July 1896	14·417	420	2,735	394,310

V.

Energy expended.	Efficiency per cent.	Number of animals employed.	Weight of animals.	Co-efficient of utility = useful work done in foot-pounds in one hour...weight of animals in lb.	Foot-tons of work per lb. weight of animal per day of eight hours.	Slope of bullock run.	Delivery of buckets in gallons.	Draught: Mean.	Draught: Maximum.
			lb.					lb.	lb.
619,500	66·6	1	1,146	360	1·930	level.	28·0	90	90
742,900 728,400 692,300	79	1	1,146	498	2·253	level.	28·0	92	22
623,784	79	2	1,438	343	1·548	level.	28·0	...	...
660,370	79	2	1,438	362	1·639	level.	28·0	...	...
1,462,600	34·25	2	1,348	371	3·871	1 in 5·28	24·2	383	410
685,080	50·0	1	700	492	3·500	1 in 2·66	23·5	...	...
771,224	70	2	1,596	338	1·724	level.	22·75	296	330
804,200	49·6	2	985	404	3·011	level.	1·776	95	95
...	...	...	...	...	...	...	...	...	...
1,132,000	47·7	2	1,320	409	3·826	1 in 7	29·1	390	420
...	...	...	...	...	...	...	...	...	...
742,196	48·23	2	774	462	3·422	1 in 5·33	24·4	327	351
2,934,000	45·57	4	2,688	497·4	3·899	1 in 3	51·48	625	700
...	...	...	...	...	...	...	...	...	...
1,383,000	33·0	4	2,058	221·8	2·400	1 in 2·5	33·88	480	510
469,762	80	3 men	308	1,220	5·446	varying.	63·20	...	...
492,887	80	3 men	331	1,191	5·306	varying.	9·50	...	...

cattle in good condition and that no time was wasted whilst the trials were in progress. The results are strictly comparable and represent the performances of each water-lift under favourable conditions.

The calculation of the efficiency of some of the water-lifts was a very simple matter since the work done by the animals could be measured just as easily as the energy which was stored in the water lifted; but in other cases, which will now be discussed, considerable difficulty has been experienced and the values tabulated are only approximate. In the see-saw water-lift of M. R. Ry. Subba Row, the efficiency when moving very slowly was found to be 59·6 per cent., but at the working speed it was impossible to determine it, and it was therefore been assumed as 50 per cent. which cannot be very far wrong. In the various forms of single mhote, the energy expended by the bullocks has been estimated by adding to the work done on the bucket rope, the work done by the bullocks in lifting their own weight up the incline during the return journey. About the latter quantity there can be no question, but about the former there is some ambiguity due to the fact that the tension in the draught rope is partly caused by the muscular exertion of the animals and partly by a portion of their weight being thrown on to the yoke during the descent of the incline. The importance of the latter quantity increases with the gradient of the run and on a very steep incline enables a pair of bullocks to exert a draught much in excess of what they are capable of on the level. If allowance were made for this, the efficiencies would work out somewhat better; as a portion of the work

done, whilst the bucket is hauled up, is due to utilizing some of the energy stored in the animals' bodies when they stand at the head of the incline; but this potential energy only represents part of the muscular energy developed in the return journey and it is in fact impossible to accurately calculate the efficiency of this lift.

Compared with the *co-efficient of utility* the actual efficiency is a matter of no great importance and it has been thought better to adopt the method given, which is an approximation to the truth, rather than a more complicated one based on assumptions which are not capable of experimental proof. The efficiency of the picottah is very difficult to estimate owing to the rapid movements of the men on the oscillating lever and to the fact that the third man, whose duty is chiefly to guide the bucket rod and empty the bucket, does very little of the work of lifting the water. It is usually stated to be 80 per cent., which is probably correct if only the energy given out by the men who work the lever be taken into the account, but it is certainly much less (about 60 per cent.), if it be considered to be a machine worked by three men.

From the experimental results presented in Table V, it seems justifiable to draw certain conclusions, of which the most important is undoubtedly that the native methods of lifting water under favourable conditions have not yet been surpassed by the best and most improved inventions of recent years. The mechanical efficiency of modern water-lifts is higher, but the mode of applying animal power, to which sufficient attention has not been paid, is distinctly inferior, save in one case, and the final result is, that as yet,

no advance has been made which will in any degree compensate for the increased cost of the new water-lifts. The see-saw water-lift of M. R. Ry. Subba Row alone seems to offer prospects of being developed into something which will be materially better than anything at present in existence. The machine examined by the water-lift committee was mechanically very imperfect, yet the *co-efficient of utility* obtained was very high, and as it demonstrated clearly the possibility of using cattle to work oscillating platforms, it must be regarded as the first step in what will probably ultimately prove the direction in which the greatest improvement can be made.

Stoney's improved double mhote is undoubtedly, from a mechanical point of view, the best water-lift that has yet been constructed and it has accordingly been made the subject of more extensive experiment than any other. The efficiency is very high and does not appear to be capable of any further improvement, but the animal or animals have to walk in a circular path and are in consequence unable to exert as powerful a draught as when walking straightforward. This is particularly the case if two bullocks are yoked to the revolving arm when the inside bullock works under great disadvantages and most of his energy appears to be consumed in *internal* work. Probably the best results would be obtained with two comparatively small bullocks yoked to separate arms, radiating from opposite sides of the drum so as to balance one another; but if this would necessitate two drivers the increased cost would more than counterbalance the improvement in the conditions of working. The time

wasted whilst the bullocks are turning round at the end of each lift is a serious defect especially on low lifts when it occupies a very considerable portion of the working cycle and it materially increases the amount of energy wasted in *internal* friction. With a single bullock of exceptional size, the *co-efficient of utility* is the highest that has been recorded but, with a pair of animals of average size, the figure is reduced by more than one-third, clearly demonstrating, if proof, indeed, be needed, that they were working under unfavourable conditions.

The Sultan water-lift was the subject of experiment on two occasions, once in Tondiarpett under very favourable circumstances as it had been in use for eight months and the animals were a very fine pair of bullocks that had been thoroughly trained to the work, and once near Bellary on the most recent type of lift, but with animals which were apparently scarcely strong enough and in consequence worked unsatisfactorily. Unfortunately, their weight could not be determined as the owner was unable to allow them to be marched into Bellary to be weighed and the observations have, therefore, not been included in the tabular statement. The lift possesses two very serious defects which are rendered more apparent by the light construction of the parts: (1) The buckets are filled and emptied by means of a valve, which is liable to get out of order and leak, and which at all times requires a strong pull to depress the lever which opens it when the full bucket is drawn up to the discharging point. (2) The draught is direct and is exceedingly heavy, being equal to the weight of water lifted,

the weight of the bucket and the force necessary to overcome the resistance of the rope passing over a number of small iron guide pulleys. The buckets are supposed to be balanced and are so except near the end of each lift when the empty bucket sinks into the water, but the friction of the ropes is so great that the weight of the empty bucket is not more than sufficient to drag the length of slack rope to which it is attached back into the well. The lift near Bellary was supplied with 30-gallon buckets and I worked it with twelve coolies through the dynamometer. The buckets discharged about 27 gallons and the pull averaged 370 lbs. towards the well and 350 lbs. away from it, and at the end of each lift rose to 500 lbs. due to the force which had to be exerted to hold the bucket of water in the air and depress the levers which open the valve against the pressure of water on it. Similar results were obtained in Tondiarpett, though the figures were smaller, as 25-gallon buckets were in use. Only the very highest class of cattle can exert such heavy draughts and even upon them the work tells very severely and they rapidly deteriorate. The draught could, of course, be lessened by the use of smaller buckets, but the outturn of water would be correspondingly decreased and the percentage of power wasted in friction would rise so much as to make patent the defects of this method of raising water. The use of larger guide pulleys, a more rigid system of construction and the introduction of a simple system of pulley blocks to diminish the draught by one-half, would increase the efficiency of this water-lift very materially, but, at the same time, would add so largely to the cost as to render it prohibitive.

The Rev. Mr. Andrew's Persian wheel, which was the first he had made, possesses the great advantage that the cattle do not have to reverse the direction of motion of the whim at frequent intervals, and that consequently no time is lost or energy wasted in useless work. It was well constructed, and though capable of minor improvements, it may be taken to represent fairly the capabilities of this class of water-lift. The continuity of action renders it extremely suitable for shallow wells in which the water level varies but little and for such conditions a smaller wheel and smaller, but more numerous buckets would undoubtedly increase the efficiency. From a ryot's point of view it is too costly, and contains too many working parts, to ever have a chance of being extensively used in this country in any other than the crude form already in use in the north.

The double mhote is inferior to Stoney's modification which has already been discussed and its defects are most conspicuous on deep wells as the motion is so slow that the leakage from the leather discharging trunks—and they always do leak more or less—becomes a serious matter, and a bucket which starts on its upward journey full of water often arrives more than half empty. It has been extensively tried in certain districts and has answered well when care was taken to keep the buckets in very good order, but that they should be so maintained for any long period is more than could be expected from the ryots of this country and the troubles from leakage have, therefore, caused the double mhote to be regarded with disfavour.

The two systems of working the single mhote as practised in Coimbatore and Bellary, and known in Northern India by the terms *Lagor* and *Kili*, respectively, have already been described. It is difficult to say what circumstances have determined the ryots in their choice between these two systems as they are often to be found working on apparently the wrong system, but it is easy to see that for shallow wells and small cattle the time lost, in detaching the cattle at the end of each lift and attaching another pair, is not compensated for by getting rid of the necessity for backing the cattle up the incline. With a shallow well and a small bucket or bag, each lift represents the expenditure of only a small amount of work whilst with a deep well and a big bucket, a large amount of work is done in each cycle of operations. With the heavy cattle, which must necessarily be employed where buckets of large capacity are used, there is probably greater difficulty experienced in getting them to back up the inclines and, therefore, more time wasted and more fatigue incurred than is usual with small cattle. Where the ryots are poor and the cattle undersized the *Lagor* method of working is often only adopted, because they cannot afford to work *Kili*, and it may be generally laid down that the first system is best suited to shallow wells, probably under 25 feet in depth, and the second system to deep wells especially when they are worked by heavy cattle. The modification in working due to M. R. Ry. Subba Row will probably be found to be of the greatest use in places where the *Kili* system is not used, either from want of a sufficient number of cattle on the part of the ryots, or because the wells are of small

capacity and too rapidly exhausted when more than a single pair of cattle are worked on them. To obtain good results with the single mhote, it is necessary that the capacity of the bucket should be suited to the size of the cattle and the gradient of the run, and it is evident that in many cases this is not so, with the result that the external work done bears a small ratio to the total muscular energy developed. Where the proper system of working is adopted and the capacity of the bucket is suited to the weight of the cattle, the single mhote is an exceedingly simple, cheap and effective water-lift and is especially convenient from the fact that a varying depth of water in the well causes absolutely no trouble whatever in working. Yet it is not without its disadvantages, and the ryots would gladly welcome any suitable substitute for leather* in the discharging trunk, so as to be able to dispense with the necessity of employing chucklers to repair it. Stout canvas has been used in some instances with great success, both in respect to durability and cheapness, and if a knowledge of this fact was widely diffused, it would confer no small benefit upon the ryots of Southern India. So far as I am aware, self-filling iron buckets have not been tried with the single mhote though there seems to be no reason why on Stoney's system, at any rate, they should not be a success.

In conclusion, it seems desirable to attempt some estimate of the cost of raising water by means of cattle. A careful study of the figures given in Table V leads me to

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* Leather manufactured by the chrome process has recently been introduced for water buckets and experience shows that it is a great improvement on the material supplied by village chucklers or country tanneries.

the conclusion that under very favourable circumstances Indian cattle will do about 1·75 foot-tons of useful work per pound-weight per day of 8 hours, so that to develop one-sixth of one horse-power the animal would have to weigh 653 lbs. and this is probably above the average weight of cattle employed on water-lifts; but assuming that these figures are approximately correct, it is not difficult to calculate what should be the cost of lifting water. A pair of animals, each doing effective work to the extent of one-sixth of a horse-power, will raise 66,000 gallons one foot high per hour; or, from a depth of 25 ft. will raise 21,120 gallons per day of 8 hours. A pair of such bullocks would be worth Rs. 100, the cost of feeding them would be at least Rs. 10 a month, and the wages of a man to look after them Rs. 5. The renewals of water buckets, ropes and the gear at the head of a well would amount to Rs. 2 a month and the depreciation in the value of the cattle to one rupee a month, making a total of Rs. 18 per month. Assuming that there are 24 working days in the month, the cost per working day amounts to 12 annas and, for this sum, 21,120 gallons of water can be lifted 25 feet, or 44,000 gallons one foot high for one anna. This means that it will cost 13 annas to raise enough water from a depth of 25 feet to cover an acre of land with one inch of water. This result is undoubtedly too low as under favourable conditions it has been determined by long experience at the Agricultural College that not more than 4,000 c. ft. or 25,000 gallons can be lifted one ft. high for one anna. Broadly it may be stated that under trial conditions the output of the water-lifts was about double

that usually obtained by the ryots with their leaky buckets and generally inferior cattle and that the cost of a one-inch watering per acre for a lift of 25 feet varies between one and a half and two rupees. It is seldom, however, that these expenses are defrayed in cash. The ryot breeds his own cattle and from the land cultivated their food is wholly or partly obtained, whilst the servant who looks after them receives the greater part of his wages in kind. Any considerable extension of well cultivation in a few years would materially change this primitive state of affairs, for there is neither capital nor labour available to allow of any rapid increase in area and both capital and labour will have to be provided. If the former is forthcoming, mechanical appliances may be confidently counted upon as efficient substitutes for both animal and human labour. To provide the data to demonstrate this, has been the object of this investigation since at a very early stage in the enquiry it became evident that little could be done to improve existing methods of applying animal power to raising water.

UNDERGROUND WATER-SUPPLY.*

DURING the past few years India has been visited by two famines over widespread areas and several severe droughts which have affected smaller but still very considerable tracts of country. The agricultural population, and those directly dependent on them, have been thrown out of employment and their slender resources being soon exhausted, in enormous numbers they have been forced to seek for the means of subsistence on the relief works which Government have opened. In good or even average years the exports of wheat and other food stuffs from the country prove that the area under cultivation is still in excess of the requirements of the rapidly-growing population. In famine years the surplus produce of the non-affected parts of the country is diverted from the export trade and carried by the railways to places where there is a local deficiency, so that in the worst years there is enough food for all and it is simply the poverty of the people that puts it beyond their reach. A succession of favourable seasons would materially improve the condition of the land-owning classes but it would lead to no accumulation of grain in the villages and the labouring classes during these years of plenty will simply increase in numbers and the next failure of the rains will find them as now—only more of them—in complete destitution.

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*_The Indian Review_, June 1900.

The problems which Indian Administrators are called upon to face in the immediate future, to combat with this deplorable state of affairs, are very difficult and the solution of them will make as heavy demands upon the energy and resources of the executive as have ever been made in the past. It is generally agreed that the most pressing necessity is the development of industrial occupations whereby new sources of wealth may be opened out and the land relieved of the excessive proportion of the population which is now entirely dependent on it. The mineral wealth of the country must be utilized to supply its own requirements, new industries must be introduced and old ones resuscitated. Instead of exporting nothing but raw materials, it will be necessary to send them out in a manufactured state and the internal trade of the empire will have to be worked up with some semblance of the energy and perseverance which the Japanese have displayed in rendering themslves independent of foreign manufacturers. The difficulties are greatly enhanced by the inability of the Government to impose protective duties, and other means of assisting nascent industries will have to be devised.

Work of this kind, however, proceeds very slowly and it will be many years, if ever, before India can be justly ranked among the manufacturing countries of the world, and in the meantime more attention must be paid to the great work which has been going on all this century, that of rendering the work of the cultivator as far as possible independent of the variations of the seasons. By anicuts and canals we have practically made use of all the water in our great rivers which can be relied on to flow continuously

through the cultivation season. By huge reservoirs or tanks many irregular sources of supply have been turned to account and nearly all the obvious sites for storing water on have been occupied. In the future, therefore, the work will be more difficult and more costly than it has been hitherto and it is hopeless to expect that the splendid financial results of the past will be again repeated. Yet in the South of India, at any rate, much can be done to economize water by improving the means of distribution and preventing the ryots from using it with actually harmful extravagance. The whole question of what is technically known as the "duty of water" requires years of careful study and experiment, and it can hardly be doubted that the time has come when a special branch of the Public Works Department should be established for the scientific investigation of this and other problems peculiar to Indian engineering. The work that is going on now at Assouan on the river Nile where a huge dam is being constructed to store up part of the flood waters in a long narrow reservoir will probably be repeated on some of our Indian rivers and the investigation and designing of projects of this kind will call for the highest possible ingenuity and skill to render them at all feasible and within the limits of our financial resources.

In fact, the storage of water is likely to become the great Indian engineering problem and attention will doubtless be paid to that portion of the rainfall which is absorbed by the earth and disappears from sight, to find its way by deep and tortuous passages to the sea. Two and one-half million wells irrigating fully ten million acres of land

attest the importance of the subterranean supplies of water and indicate that in this direction there are immense possibilities. Underground water has never in India, been studied properly by engineers or geologists, and wells are sunk, in a happy-go-lucky manner to a haphazard depth. They are constructed with primitive appliances and at small cost. Expectations are not usually great and as they are generally realized the people are content. Some wells dry up in the hot weather, some wells always respond to the demands that are made upon them and nothing is really known about their capacity to supply water. A few elementary calculations, however, will show that the quantity of water drawn from most wells is but an insignificant fraction of the stores that must be below and which are continuously passing away through permeable strata till they ultimately reach the sea. Where the average rainfall is 30 inches per annum we may assume that one-third of this sinks below the surface and that, therefore, each square mile of land receives 640,000 tons of water. If but one-half of this quantity could be extracted from the earth by pumping from wells it would yield a continuous supply of one cubic foot per second for 136 days, which, with economical use, would fully suffice for the irrigation of 250 acres. Twenty-one mhotes and twenty-one pairs of bullocks working steadily for eight hours a day would draw out this quantity of water from a depth of 20 feet. Now there are no data available as to the number of wells per square mile. In parts of such districts as Coimbatore they are very numerous and the total yield of water from them may exceed one cubic foot per second

per square mile, but over the greater part of India nothing approaching this quantity is obtained. From such data as are available, I estimate that wells in India yield about 40,000 cubic feet per second, a very large quantity of water but equal to only one-thirty-fifth of a cubic foot per second from the 1,400,000 square miles of total superficial area. Over a great part of India the rainfall is more than 30 inches a year and we know nothing as to what becomes of the vast quantity of water which annually sinks into the earth. We know that in some districts there are many wells with a good supply of water, in others few wells and the yield very precarious. Sometimes the reason is obvious from the nature of the surface and the configuration of the ground but in most cases it is just the reverse and many wells have been sunk by engineers in what were considered likely spots and have turned out useless.

The great majority of wells in this Presidency range from 20 to 40 feet in depth. They, therefore, derive their supply of water, with the exception of such wells as actually tap under-ground springs, from an inverted conical mass of earth, the axis of which is the well and the vertex the water-level. Each well is the centre of a certain mass of earth which absorbs water from the surface percolation until it is saturated and any excess slowly moves along the lines of least resistance. The well alters the direction of these lines and some water flows into it, but the greater part of the water sinks vertically till it reaches impervious strata. The deeper the wells the greater is their action in deflecting the lines of sub-soil flow and in some cases there is no doubt that vigorous pumping after heavy rain would

materially increase the volume of the cone influenced by the well. This, of course, is the time when wells are left alone and advantage is not taken of such opportunities to form lines of sub-soil flow towards the well.

Artesian wells have been carefully studied in many lands but wells of the types found in India have been neglected and we know practically very little about them. Isolated experiments will not teach us much owing to our inability to see what is going on inside the cone of influence round the well. The intelligent ryots of the country have probably a good deal of information about the behaviour of their own wells and of those belonging to their neighbours and skilful examination of villagers in well-irrigation districts might lead to the collection of some useful preliminary data which might serve as the starting point for further enquiries. Very few wells exist which are known to yield enough water to offer any inducement to employ mechanical arrangements for pumping water from them. It is easy to see why this is so. The depth of the well is limited by the fact that the primitive methods of sinking in vogue among the ryots prevent them going more than a few feet below the hot weather level of the water. With an engine and pump to keep the well dry much greater depths might be attained and possibly the supply of water enormously increased.

It is generally considered that mechanical methods of pumping water for irrigation are too expensive to be employed and it is generally supposed that animal power is the only means available. Let us consider an imaginary case and then see how far the conditions are likely to be

realized in practice. The well is a deep one and yields half a cubic foot per second, with a water-level about 40 feet below the ground. It is provided with an oil engine and a pump. The engine is only worked for 16 hours per day and, therefore, has to lift 250 gallons per minute throughout that period.

Allowing an efficiency of 40 per cent. for the gearing and centrifugal pump, the engine would have to develop $7\frac{1}{2}$ brake-horse-power and would consume one gallon of kerosine oil, costing 7 annas per hour. The monthly expense which such an engine would entail may be taken as follows:

	Rs.
Fuel for 24 days at Rs. 7 per day ..	168
Wages for 2 drivers at Rs. 12 & 10 per month	22
Lubricating oil, waste and stores ..	15
Interest and depreciation on capital outlay, cost of repairs, etc., at $12\frac{1}{2}$ per cent. per annum on Rs. 3,000 ..	32
Rs.	237

Compare this with the cost of working with cattle. In the paper on "Water-Lifts" we obtained the result that to work a mhote for 8 hours a day required one pair of cattle worth Rs. 100 and that they would do effective work equivalent to one-third of a horse-power. In this case the oil engine develops $7\frac{1}{2}$ horse-power of which 40 per cent. is used effectively so that the work done by the engine in any given time is equal to that of 9 pairs of cattle but the

engine works twice as many hours per day as do the cattle and is, threfore, equivalent to 18 pairs of cattle. The cost of keeping each pair of cattle was found to be Rs. 18 per month or for 18 pairs Rs. 324 per month. With the oil engine and pump, therefore, a saving of Rs. 87 per month can be effected and the cost of raising water reduced by about 25 per cent. Till comparatively recently this was the best result that could be put forward in favour of mechanical methods of raising water but now it is possible to make out a much lower estimate of the cost of generating power with oil engines owing to the feasibility of using crude petroleum instead of kerosine oil. At the present time the former costs as. 3 per gallon in Madras as compared with as. 7 per gallon for kerosine oil, and from careful experiments on an 8½ horse-power Hornsby-Ackryd oil engine at the School of Arts it was found that 8 gallons of liquid fuel did as much work as 9 gallons of kerosine oil so that the reduction in cost of fuel is in the ratio of 24 to 63. Applying this to the estimate given above of the working expenses of the oil engine, the cost of fuel is reduced from Rs. 168 to 66 per month and the entire cost of running the engine is reduced to Rs. 135 per month as compared with Rs. 324 for cattle. It can, therefore, be fairly claimed that by the use of oil engines and pumps the cost of raising water can be reduced to less than one-half the present rates.

It would be useless to follow up the comparison between the two methods of pumping any further. It is sufficiently demonstrated that the employment of oil engines for pumping water is a perfectly practical method and can be

employed with advantage whenever the quantity of water to be dealt with amounts to half a cubic foot per second. The initial capital outlay is beyond the means of the ordinary ryot but it is not beyond those of many land owners, and if only sufficient interest could be aroused among them in the improvement of their estates, the ultimate benefit to the country at large would be incalculable.

The two and one-half million wells in India represent a capital outlay not far short of forty crores of rupees and what is wanted almost as much as new wells is the systematic improvement of those already in existence. Many are probably far too shallow and others are too small and do not present a sufficient area for percolation. To jump holes from 10 to 30 feet in depth and a few inches in diameter at the bottom of some wells is not a very difficult matter and the value of the tube would probably be greatly enhanced if the rock at the bottom were loosened by the explosion of two or three small charges of dynamite. To run short adits in the hot weather from the bottoms of many wells is perfectly feasible and both methods, if tried, would yield results far in excess of the cost. Yet these things are not done because the ryots do not know of their value; and even if they did, they would regard them with suspicion as innovations to be classed with many other attempts, by Europeans, at agricultural improvements. These are suggestions which have deen tried in other places with success but so little do we know about this subject that I put them forward with diffidence and simply with a view to drawing attention to the urgent necessity which now exists

for a systematic attempt to investigate the conditions under which the stores of subterranean water exist.

The matter is one surrounded with difficulties and it is only by an intelligent co-operation of wealthy land-owners, who can afford to install engines and pumps for the irrigation of their lands or the cultivation of their gardens, with persons possessing a sufficient knowledge of engineering and geology that anything can be done. In this country we rely too much upon official efforts and too little is done by the enterprise of educated and enlightened private individuals. In England, the late Mr. G. J. Symonds enlisted the services of thousands of meteorological observers and established a system of recording data connected with rainfall in the British Isles which has proved of national importance. The agricultural experiments carried out on the Rothamsted farm by Sir John Lawes and Sir Henry Gilbert for more than half a century is another instance of private work which has done much to convert rule of thumb practice into a scientific procedure and farming all over the world has greatly benefited from their disinterested labours. Nothing of this kind has ever been attempted in India and I venture to think that the problems presented by well irrigation would be a fitting subject for investigation and one in which many workers might profitably engage themselves. I have endeavoured to show how little is really known and how much is left to chance and I cannot doubt that if the work were started and the areas under observation gradually enlarged, it would result in additions to our knowledge which would prove of great benefit to the whole community.

WELL IRRIGATION.*

IN June 1900 I contributed a short article to this Review on the very important subject of "Underground Water-supply" in which I endeavoured to show that the information available regarding the ultimate disposal of the rainfall in India was very limited, and that consequently it was desirable to scientifically study the question with a view to utilizing a much larger proportion of the subterranean water for irrigation than is at present done. As a preliminary step it was obvious that more powerful and cheaper methods of lifting water than by water-lifts worked by cattle were essential and I showed that the oil engine when employed to pump from a well yielding on an average throughout the day half a cubic foot per second or 190 gallons per minute was considerably cheaper and more convenient than any form of water-lift worked by means of animal-power.

The importance of well irrigation was fully recognized by the Irrigation Commission and a large amount of evidence was tendered by many witnesses. The report of the Commission may be expected to contain practically a complete summary of all the information available and will serve as a starting point for further investigations. Funds have already been placed at the disposal of the

* *The Indian Review*, August 1902.

Madras Government for experimental work in this direction and during the next few years there is no doubt that a serious effort will be made to render available for agriculture a very large quantity of the water which now runs to waste beneath the surface of the earth.

In the year 1900-01, there were in the Madras Presidency 615,520 wells from which water is drawn for irrigation and the area of cultivated land partially or entirely dependent upon them was 1,171,346 acres of first crop and 498,878 acres of second crop. Each well on the average supplied water to only 2 acres of land and naturally the question arises—Is full use made of the stores of water below the soil? In many cases, possibly in a numerical majority of the cases, there is little doubt that all the available supply is utilized but in what may perhaps be a comparatively insignificant minority of wells the available supply is enormously greater than the present demand and vast quantities of water remain unused. It must be within the personal knowledge of most people that there are wells which yield a good supply of water throughout the year and never dry up even in years of severe drought. Such wells should be examined and attempts should be made to pump them dry. Many wells are only made use of to the extent that tanks would be, if they were only provided with high level sluices through which the upper water in the tank, and that only, could pass through the bund into the irrigation channels. In the south of India well-sinking is a very primitive business and the better the supply of water, generally the shallower the well. A ryot wants a well and, having selected a spot which he thinks suitable, he sets to

work and either sinks a hollow cylinder of brickwork into the ground till water in sufficient quantity to satisfy his expectations is reached, or he excavates a big rectangular hole in the disintegrated rock which forms the sub-soil and goes on deepening it till the inflow of water is greater than can be dealt with by the modest water-lifting appliances at his disposal. Year after year in the hot weather when the water level is low, he may increase the depth by adding to the number of mhotes on the well and in this way many valuable water-yielding wells have been sunk. Let us suppose, however, that the unwatering of the well in the hot weather is accomplished by a powerful engine and pump, the work of excavating will be easy and the depth may be rapidly increased till either the inflow is greater than can be dealt with or practical considerations clearly indicate that it is not worth while to go any deeper. For water to flow into a well the level in the well must be lower than in the sub-soil and the greater the difference in level, the greater is the force tending to make the water flow into the well. But the lower the level in the well, the greater is the amount of work which has to be done to raise the water above the surface and ryots prefer numerous shallow wells to a few deep ones. The number of cattle employed in lifting water is enormous and it is improbable that any great extension of well cultivation can take place under the present system for lack of animal power to do the necessary work of extracting the water. A ryot must have cattle and while the crops are growing they can be profitably employed in raising water, but directly he has

to keep cattle specially for the purpose, well irrigation becomes expensive and unprofitable. A pair of good serviceable bullocks in constant work cannot be kept for less than Rs. 18 per month including the wages of a driver and the work they do can be far more cheaply performed by a good oil engine or steam engine. But these machines, even when of the smallest size practicable, are far too big for the work of drawing water from ordinary wells and they can only be employed when the conditions are unusual in respect to the volume of water to be obtained from a well. A $3\frac{1}{2}$ horse-power oil engine, which is the smallest size it is advisable to employ, can be worked for 16 hours a day at a cost of $2\frac{1}{2}$ rupees and will do as much work in lifting water as 8 pairs of good bullocks costing Rs. 144 a month. Allowing for repairs, depreciation and interest, I have no hesitation in stating that the cost of pumping by an oil engine of this size, driving a centrifugal pump, is almost exactly one-half what it is when bullocks are used, provided only that there is sufficient work to keep the engine fully employed.

Before developing further the idea of employing oil engines for well irrigation I propose to briefly describe an experiment now in progress. About 6 miles from Chingleput is a small pariah settlement founded by Mr. Andrew of the Free Church of Scotland Mission. About 50 acres of land are under cultivation and the crops are watered by 5 wells which have been sunk since the settlement was started about eight years ago. Greatly interested in the question of well irrigation Mr. Andrew

offered to allow me to conduct experiments on his wells and with the assistance of funds placed at my disposal by the Madras Government, at the instance of the Chief Engineer for Irrigation, Colonel Smart, R.E., I have been able to put to the test of practical working the idea of using oil engines. I selected what was supposed to be the best well on the settlement and at the beginning of March I tried to unwater it by working a Persian wheel continuously night and day by means of relays of bullocks. I soon found it desirable to increase the pumping power and accordingly a picottah was set up and worked by gangs of coolies night and day. The draught on the well amounted to about 2,500 gallons per hour or allowing for irregularities to between fifty and sixty thousand gallons per day. This resulted in a gradual lowering of the water-level till the depression amounted to $5\frac{1}{2}$ feet, when the level became stationary and the inflow was equal to the amount withdrawn. Arrangements were then made with Messrs. Massey & Co., of Madras, to supply a $3\frac{1}{2}$ horse-power Hornsby-Ackroyd oil engine and a 3-inch centrifugal pump, the combination being capable of lifting 170 gallons of water per minute to a height of 30 feet. Pumping was started at the end of March and in a few hours the well was emptied. An attempt was then made to deepen the well and a central hole 15 feet in diameter was sunk 7 feet when hard rock was met with. To increase the area through which percolation could take place adits were run horizontally from the bottom of the well through the partially disintegrated rock. Four were started, but two of them had

to be given up before they had been run out 10 feet on account of boulders, the other two were carried outwards about 25 feet and 20 feet respectively, and the percolation through their sides forms the main source of inflow to the well. The cost of the adits was Re. 1 per foot run, and they were stopped as soon as the rate for excavating them rose above that amount. The result of the operations was to increase the inflow from 40 to 66 gallons per minute or from 60,000 to nearly 100,000 gallons per day. Pumping has continued all through the hot weather and the inflow has somewhat decreased. On the 20th July it was measured and found to be about 67,000 gallons per day. With the advent of the rains it is expected that the inflow will materially increase but how much is quite uncertain. At present the engine runs nine hours a day, in three periods of from two to three hours each. When pumping ceases, the flow of water accumulates in the well and at the beginning of each working interval there is about 5 feet of water to be removed. The average lift is 25 feet and the engine consumes about 2 gallons of oil per day costing as. 12. The wages of the driver are Rs. 12 per month, so that the total cost of running the engine including the cost of stores amounts to only Rs. 40 per month. Later on with longer running hours it may amount to Rs. 60 per month and for this sum 50 acres of dry cultivation will be fully supplied with water. The capital outlay on the engine and pump and the cost of fixing the same amounted to Rs. 2,500 and an allowance of Rs. 40 per month for interest, repairs and depreciation will be a

very liberal provision, making the total monthly charges Rs. 100 when running and about Rs. 50 when standing. Assuming that water is required for eight months in the year, the total cost of this engine and pump will be Rs. 1,000 per annum. For this sum 50 acres of dry crop will be watered and I am inclined to think that possibly, with the supply of water to be expected, the area may be much larger but only a continuance of the experiment over several years will enable this to be definitely determined. The conditions under which this experiment is being conducted are by no means favourable and much better results could be obtained in many places. The well yields a fair supply of water, but there are undoubtedly very many which would give double the supply. The engine and pump worked to their maximum capacity would raise 250,000 gallons a day to a height of 30 feet or nearly half a cubic foot per second, sufficient for from 100 to 125 acres of dry cultivation. Under such circumstances, the cost of supplying water to the land would not amount to more than Rs. 12 per acre per annum. This is a result so very satisfactory that when it becomes known and fully realized it ought to lead to an immense employment of these modern methods of lifting water.

It is well known to engineers that the cost of generating a unit of power rapidly decreases as the amount of power generated by a single engine increases. In view, therefore, of the fact that the great majority of wells are unable to yield sufficient water to give adequate employment to even the smallest engines, it has occurred to me that possibly

large tracts of land could be supplied with water from wells by electrically driven centrifugal pumps, the power being generated at a central station and distributed by a net work of overhead conductors. From an engineering point of view the problem is a comparatively simple one and its practicability simply depends upon the cost of the installation both as regards capital outlay and working expenses. I have, therefore, obtained estimates of the cost of the machinery from well-known firms in England and with the information thus obtained I have worked out two imaginary schemes assuming conditions that could be realized in many places in this Presidency. The first scheme is a comparatively small one for the irrigation of five or six hundred acres. All the land is assumed to be situated within a rectangle 2 miles long and 1 mile wide. The water-supply is derived from twelve wells scattered over the area. Each well may be assumed to cost Rs. 500 though under favourable conditions, they would not cost more than half this amount as the depth is not to exceed 35 feet. The water would be lifted by a 3 inch centrifugal pump driven by a direct coupled 3½ horse-power electro-motor, the pump and motor complete and fixed in the well costing Rs. 750. The current would be supplied from a generating station situated near the centre of the area and 5 miles of overhead conductors costing about Rs. 650 per mile, would be required for distributing the energy. The generating station might be supplied with a steam engine and boiler costing Rs. 4,000 or with an oil engine, in which liquid fuel could be used, of the same power costing Rs. 5,000, driving a dynamo costing Rs. 1,800 which

would give out a current of 27 amperes at 550 volts pressure equivalent to 20 electrical horse-power and capable of driving 4 of the pumps under full load, or 5 under the average load which would come upon them. Each pump would discharge 150 gallons per minute, so that with 5 pumps going the supply of water would be 2 cubic feet per second or sufficient for 500 acres of land. The method of working would be to run a motor till the well was emptied and then shut off the current and allow it to fill up by percolation, whilst the current was employed in driving another motor in another well. With 5 motors running out of 12, water would be drawn from each well an average of 10 hours per day. Including all items, the total cost of the installation would be as follows :—

Engine house	Rs.	2,600
Engine and dynamo	,,	6,800
Switch board, etc.	,,	500
12 Wells at 500/	,,	6,000
12 Pumps and motors at 750/ ..	,,	9,000
5 Miles of line at 650/ per mile ..	,,	3,250
Contingencies 10 o/o	,,	2,850
Total ..		31,000

The working expenses would be as follows :—

Repairs, interest and depreciation at $12\frac{1}{2}$ o/o	Rs.	3,875
Liquid fuel at As. 3 per gallon at 2 gallons. per hour for 5,000 hours	,,	1,875
Superintendence and labour Rs. 130 per mensem for 12 months	,,	1,560
Miscellaneous stores . ..	,,	200
Total ..		7,510

This is the cost of watering 500 acres of land would amount to Rs. 15 per acre per annum, the land being under cultivation practically the whole time. This is far too high a charge for ordinary wet crops, but it is by no means excessive for garden cultivation, such as is practised in agriculturally advanced districts like Coimbatore. For projects of this kind to pay, it naturally follows that when all the resources of modern engineering are devoted to the problem of supplying water and a considerable outlay in machinery and plant is involved, the agricultural operations must be of a similar character and the cultivators must be prepared to put capital and labour into their fields to obtain the best possible results. The selection and rotation of crops must be judicious, the lands must be well manured and in general terms what is known as *intense* cultivation must be practised.

Let us now consider the possibilities of operating on a much larger scale and for this purpose we will assume that there is a strip of land about 10 miles long and from one to two miles wide lying alongside a river channel. Such a piece of country actually exists on the Palar not far from Chingleput. The land near the river will probably be at a slightly higher level than further away and as the wells will draw their water-supply mainly from the subterranean flow of the river they will all be situated near the river bank. The wells will be sunk near the river bank at an average distance apart of one-fourth of a mile. In all, there will be 40 such wells and the power station will be situated in the middle, with 20 wells on either side, the most distant well being $4\frac{7}{8}$ miles off. Assuming that the

average inflow into each well is half a cubic foot per second and that the average lift is 30 feet the total actual work which will have to be done by the pumps will be 68 horse-power. To determine the power required at the generating station, we may make the following assumptions regarding the efficiency of each part of the system of power distribution :—

Efficiency of dynamo	.. ..	90 per cent.
Efficiency of transmission	.. ..	90 per cent.
Do. motor	.. ..	80 ,,
Do. pump	.. ..	45 ,,

Combined efficiency of whole system 30 per cent. so that the engines will have to furnish 227 horse-power. The following estimate of the cost of the plant may be taken as approximately accurate :—

	Rs.
Engines	45,000
Dynamo	9,000
Engine house	7,500
Switch board and fittings	2,000
40 wells at Rs. 500 each	20,000
40 motors and pumps at Rs. 750 each	30,000
Overhead conductors 10 miles at Rs. 1,500 a mile	15,000
Contingencies, 10 per cent. ..	13,700
Total ..	1,42,200.

The working expenses on an assumed running of 5,000 hours per annum would be :—

			Rs.
Fuel for engines	..	..	11,250
Superintendence and labour		..	3,600
Repairs, interest and depreciation at $12\frac{1}{2}$ per cent.	..	..	17,775
Miscellaneous stores	..	..	1,000
Total		..	33,625

The area that could be irrigated would be between four and five thousand acres and the annual charge for pumping would amount to not more than Rs. 8 per acre. The case considered is perhaps a favourable one, but without doubt a careful examination of the country would reveal many such, and it is eminently desirable that advantage should be taken of the natural facilities where such exist.

So far we have only considered the question of well irrigation when the power is supplied by oil or liquid fuel engines, but it is open to us to go one step further and consider what use can be made of water-power which in certain districts is available in vast quantities throughout the greater part of the year. Without going into details, one or two general facts may be noted which tend to show that there is a wide field open to engineers in India in utilizing the power of water falls to lift water from wells over very extended areas. For industrial operations a continuous supply of water all the year through is generally essential, and expensive storage works have to be con-

structed to tide over the period of scarcity of water during the hot months of the year. When the water-power is to be used for pumping water from wells the failure of the supply of power during the hot weather is of little or no importance as the cultivation can be so arranged that the land requires no water at that season. Water-power can, therefore, be provided at much less expense for such schemes as we are now discussing, and if it be a profitable undertaking to generate power at the Cauvery falls and carry it over 90 miles to the Kolar mines, under onerous conditions regarding failure of the supply, it is obvious that it will be still more profitable to utilize water-power under the much less exacting conditions which would prevail in irrigation pumping.

The report of the committee on utilization of water-power at Periyar stated that electric energy could be delivered in Madura 80 miles away for Rs. 22–8–0 per horse-power per annum and in Madras for double that sum or Rs. 45. It is more than doubtful, however, if this result could under any circumstances be attained and it would be safer to assume that the actul cost would be about three times as much but even then it would appear to be practicable to lift water from wells or rivers by the agency of electrically transmitted energy over the greater part of the South of India. The minimum power available at the Periyar during ten months of the year is officially stated to be 30,000 horse-power and there is reason to suppose that the efficiency of the whole system of generation, transmission and utilization would be one-fourth, so that 7,500 horse-power woud be the work actually accounted for by

the water lifted. On an average lift of 40 feet this would be equivalent to 1,650 cubic feet per second or sufficient for 412,500 acres of land. At Rs. 10 per acre for annual charges this would amount to $41\frac{1}{4}$ lakhs and would permit of a capital expenditure of at least 3 crores of rupees, probably a much larger sum than would actually be needed.

I have drawn attention to the possibilities attendant on the utilization of water-power for pumping purposes because ultimately I think they will be realized on an exceedingly big scale, but that day is yet distant and the business of immediate practical importance is the smaller schemes which I have outlined in this note. They involve but a small expenditure, each one started and proving successful adds to the store of information we must gather about underground water and places us in a position to ensure that in subsequent undertakings the risk of failure will be a constantly diminishing quantity. The exceeding simplicity of working, characteristic of good oil engines and their remarkable economy in the matter of fuel has changed the conditions under which water-lifting can be undertaken. It is necessary to reconsider the position and demonstrate by practical working that the primitive appliances of the ryot can be superseded by methods of water-lifting so greatly superior as to open out entirely new possibilities regarding the utilization of subterranean water.

NOTE ON IRRIGATION BY PUMPING FROM A WELL AT MELROSAPURAM, 1902–1905.

IN the following note all measurements of water are stated in *cubic feet*, and the unit of time which it is found most convenient to employ is the *hour*. One cubic foot per second (abbreviated to *cusec*) is equal to 3,600 cubic feet per hour and an acre of land requires 3,630 cubic feet to cover it to a depth of 1 inch, so that a cusec. is very nearly equal to 1 acre-inch per hour or 2 acre-feet per day. This is a very convenient relationship, because in well cultivation at each watering the land is covered to a depth of 1 inch. If, in the future, oil engines and pumps are extensively used for well irrigation in India, it is almost certain that the 3-inch centrifugal pump will be the size most largely employed and the capacity of such a pump when worked at a proper speed is practically one-half a cusec. or an acre-inch in 2 hours, so that such a pump will water 6 acres per day of 12 hours and will be suitable for areas ranging from 30 to 50 acres.

Six miles to the North of Chingleput and a mile to the East of the South Indian Railway is a small Panchama settlement which was founded in 1893 by the Rev. Mr. Andrew of the Free Church of Scotland Mission. At the time the experiments commenced about 50 acres of land had been brought under cultivation and the crops were

watered by 5 wells, sunk since the settlement was first started. Mr. Andrew has always taken a great interest in well irrigation and his design of Persian wheel to suit local requirements was tested by Mr. Chatterton in February 1896 and the results are recorded in Bulletin No. 35. In November 1901 the settlement was visited by Colonel Smart, the then Chief Engineer for Irrigation, Mr. Benson, the Deputy Director of Agriculture, and Mr. Chatterton, the Professor of Engineering in Madras, and it was then decided in consultation with Mr. Andrew that the well marked A on the site plan was likely to prove suitable for experiments in pumping and Mr. Andrew agreed to carry them out under the general direction of Mr. Chatterton.

The object of the experiments was (1) to ascertain what quantity of water such a well would yield when worked to its maximum capacity, (2) to determine what increased quantity of water could be obtained from the well by deepening it and by any other devices which might suggest themselves in the course of the experiments, (3) to employ an oil-engine and centrifugal pump to lift the water from the well and to ascertain the cost of such work and whether it would be feasible to employ such motors and pumps wherever there was a sufficient supply of water to give them employment.

In G. O., No. 40-I., dated the 10th January 1902, a sum of Rs. 1,000 was placed at Mr. Chatterton's disposal and on the 4th of March pumping was started from the well with the water-lift erected there by the Rev. Mr. Andrew. Relays of cattle were provided and the lift was worked day and night till the 15th of March. At the end

of the first day it was perfectly obvious that the lift with the capacity of 250 cubic feet per hour could produce little effect on the well. A piccotah was accordingly set up to work alongside which probably doubled the draught on the well. There were no means of making accurate measurements of the discharge, but with both lifts going the quantity of water raised from the well was about 400 cubic feet per hour, or 10,000 cubic feet per day. This resulted in the gradual lowering of the water-level till the depression amounted to 5½ feet when the level became stationary and the inflow was equal to the amount withdrawn. Arrangements were then made with Messrs. Massey & Co., of Madras, to supply a 3½ H. P. Hornsby-Ackroyd oil-engine and a 3-inch centrifugal pump made by Messrs. Gwynne & Co. The engine and pump started work on the 27th March and in a few hours emptied the well, although the inflow of water soon restored the level when pumping ceased.

The well was circular about 21 feet in diameter and 21 feet deep and to increase the inflow a central hole 15 feet in diameter was excavated to a depth of 7 feet when hard rock was met with, and it seemed useless to proceed any further. From the bottom of the well four horizontal adits were then excavated in the partially disintegrated rock. The adits radiate from the centre at right angles to one another and are 5 feet 6 inches high and 2 feet wide and ultimately attained the length of 35 feet, 25 feet, 10 feet and 8 feet, respectively. Two of them were abandoned after being run a short distance owing to huge boulders of hard rock blocking the way. These adits increased the inflow from 400 cubic feet per hour to about 670 cubic

feet. Pumping was continued throughout the hot weather and the inflow gradually decreased. On the 20th of July it was measured and found to be about 450 cubic feet per hour. At this time of the year it was only practicable to run the engine for periods of two or three hours at a time, as the pump was capable of lifting about 1,440 cubic feet per hour, whilst the inflow was less than a third of this quantity. When the engine was at rest the water accumulated in the well at a gradually decreasing rate, due to the gradual diminution of the difference between the level of the water in the surrounding rock and that in the well.

Till the end of March 1903 the water raised from the well was utilised in the settlement without any change in the methods of cultivation which had hitherto been pursued. It was then arranged that the engine and pump should be handed over to Mr. Andrew and that he should work the same at his own cost, utilising the water for the irrigation of more profitable crops than had hitherto been grown. On the 7th and 8th February 1903, and again on the 28th of the same month measurements were made of the rise and fall in the water level in the well due to percolation and pumping. The figures obtained are given in Tables I and II of Appendix I. As the volume of water in the well at any given level was fairly accurately known, it has been possible to calculate the rate of percolation and the rate of pumping and these figures have been entered in the table. Similar experiments were subsequently made on the 26th September, the 24th December 1903, on the 6th and 7th of April 1904, and again on the 7th of April 1905.

These results are shown in Tables III, IV, V and VI of the same Appendix.

It will be convenient to examine these figures in some detail. On the 7th February 1903 at the commencement of the observations there was 3·42 feet of water in the well and the rate of percolation during the first hour averaged 540 cubic feet. At the end of four hours the depth of water in the well was 8·33 feet and the average rate of percolation during the last hour was 307 cubic feet per hour. During the night the depth increased to 12·33 feet which level was reached 10·78 hours from the commencement of the measurements. The engine was then started and it lowered the water-level in the well over 5 feet in the course of the first hour, which, allowing for a slight inflow during that time, showed that the discharge of the pump was 1,880 c. ft. per hour. As the depth decreased the load on the pump increased and its discharge diminished. In $3\frac{1}{4}$ hours the well was emptied and, the engine being stopped, percolation again commenced to refill it. At the end of one hour the water had risen to a level of $2\frac{1}{4}$ feet showing the rate of percolation equal to 590 c.ft. per hour. But as the bottom of the well is somewhat irregular this figure is not very reliable and it is probably a little too high. During the next two hours the rate of percolation averaged 488 c.ft. per hour, and in the following half an hour the water rose 1·08 feet equivalent to a rate of percolation of 670 c.ft. per hour. This result is inexplicable. After a rest of $3\frac{1}{2}$ hours the engine was again started and emptied the well in 2·28 hours. When the pump ceased working, measurements of the rate of

percolation were continued for four hours and the figures obtained are much more regular than in the previous case. The observations made on the 28th February were of a very similar character, and it is evident that during the three weeks' interval no material change had taken place in the condition of the well. These observations show that the rate of percolation varies with the level of water in the well and is greatest when the well is completely emptied. Assuming that not more than 3 feet of water was allowed to accumulate at the bottom of the well, the inflow would have been about 512 c.ft. per hour. Similarly from the measurements made in September and December it is evident that the rate of inflow had increased to 1,100 c.ft. per hour, and from those of April 1904 that it had then fallen to 610 c.ft. per hour.

It was obvious from these observations that, if the maximum quantity of water was to be obtained from the well, the level should not be allowed to rise much above 4 or 5 feet, and in ordinary times this would mean stopping and starting the engine a considerable number of times in the course of the 24 hours. To get over this difficulty it was suggested to Mr. Andrew that he should excavate a much larger well alongside the existing well and connect the two by extending one of the adits. Some assistance was obtained from Government and a well 30 feet in diameter and 30 feet deep has been dug, so that at the bottom of the well the area of the cross section is now 1,044 sq. feet. The result is that a large quantity of water can accumulate in the subterranean reservoir without materially raising the back pressure which prevents inflow to the well. The new

well adds very largely to the area through which percolation can take place, but its most important function is to act as a subterranean reservoir in which percolation can be stored. Owing to the failure of the north-east rains at the end of last year it was impossible to obtain any comparison in 1904 with the results obtained in September and December 1903 previous to its construction and the observations which were made on the 7th April of this year compare unfavourably with those of the previous year, but they are extremely interesting as showing how well the supply of water is maintained and how it is possible to economically employ an engine and pump, although the steady inflow to the well is comparatively small. The observations taken on the 7th of April are given in Table VI of Appendix I, together with the calculations to determine the rate of inflow. This proved to be 336 c. ft. per hour between the levels of 28 and 29 feet from the surface of the ground.

In 1904 a measuring tank was constructed 10 feet square and 3 feet deep, so that the discharge of the pump might at any time be accurately determined by turning the flow of water into this tank and noting the time taken to fill it. Unfortunately while building this tank an accident happened to the centrifugal pump whereby the pump casing was badly cracked and the various tests which were subsequently made on the imperfectly-repaired pump by Mr. Andrew and by Mr. Rajagopalasawmi Mudaliar do not possess the value they would have done, had the pump been in thoroughly good working order. These results are, however, given in Table VII of Appendix I.

In Tables I, III and IV the discharge of the pump before it was damaged has been calculated and these results were plotted and a curve obtained from which the values given in the lower half of Table VII have been taken. A few tests have been made of the new pump and these are embodied in Table VIII. The data in this case have been fairly accurately determined with a view to ascertain the maximum speed at which the pump could be run with the $3\frac{1}{2}$ H.P. engine.

During the two years between the 31st March 1903 and the 1st April 1905 a record has been kept of the number of hours the engine has worked and of the expenditure incurred, and from these data it is possible to determine what has been the cost of lifting water at Melrosapuram. The details are given in Tables A to H and J of Appendix II and the results obtained are as follow :—

Tables A and E.

In 1903–1904 the pump was worked for 831 hours at a cost of Rs. 746–8–4, of which amount it should be observed that no less than Rs. 300 is allowed for interest and depreciation. The cost per hour amounts to 14·38 annas and for that sum it may be approximately assumed that 1,440 c.ft. of water has been raised 25 feet. This is undoubtedly a very high rate. But it is mainly due to the very small number of hours during which the engine worked and the very large number of times that it was started and stopped. In all, the engine was started 334 times and the average duration of each run was in consequence only $2\frac{1}{2}$ hours, so that the amount of fuel used in starting the engine was out of all proportion to the amount of work done. This unsatis-

factory result, however, has a more pleasing aspect from the irrigator's point of view as the small number of hours which it was necessary to run the pump was due to the fact that the season as a whole was an extremely favourable one and the assistance of the pump was only required to a very moderate extent.

In 1904–1905 the conditions were materially different. The rainfall throughout the year was slight, the north-east monsoon was a complete failure and it was necessary to withdraw from the well all the water that could possibly be obtained. The engine was started 568 times and ran for 2,074 hours giving an average of 3·65 hours for each run. The working expenses amounted to Rs. 1,088–1–10 equivalent to 8·39 annas per hour. This is a very material reduction upon the figures for the previous year, but it is by no means satisfactory and it should yet be possible to further reduce them.

Tables B and F.

In 1903–1904 the consumption of oil amounted to 786 gallons or 0·945 gallons per hour. In 1904–1905, 1,691 gallons of oil were required to run the engine 2,074 hours giving an average consumption of 0·815 gallons per hour. During the first year practically nothing but kerosine-oil was used; but in 1904-1905, 728 gallons of liquid fuel costing 3·15 annas per gallon were mixed with 963 gallons of kerosine-oil costing 6·7 annas per gallon. An oil-engine which develops 3½ H.P. with kerosine-oil cannot be reckoned to be of more than 3 H.P. with liquid fuel and it unfortunately happens that the power required to drive the centrifugal pump at Melrosapuram when the water is low in the well

Tables G and H.

is fully $3\frac{1}{2}$ H.P., so that liquid fuel by itself cannot be used. If liquid fuel alone had been used there would have been a saving of Rs. 213 in the cost of fuel and the cost of working the engine per hour would have been reduced to 6·75 annas.

The damaged pump has been replaced by a new Worthington 3-inch centrifugal, which the makers claim to possess a much greater efficiency than was obtainable from the old pump. If this proves correct, the engine will probably be able to work with liquid fuel entirely and next year there ought to be a further reduction in the cost of working, partly on account of the greater efficiency of the pump, partly on account of the use of liquid fuel and partly because it will be possible, now that the storage reservoir is completed, to run the engine for much longer periods without stopping. It is interesting to note that the oil-engine is in charge of a young Panchama who belongs to the settlement. He was trained in engine-driving at the School of Arts for a few months and is capable of running the engine fairly well, so long as nothing gets out of order.

With kerosine-oil the engine is very little trouble to look after but when liquid fuel is used it is necessary to clean the vaporiser every day and this entails a certain amount of extra labour, but very small compared with the great saving effected in the cost of working the engine. Kerosine-oil can be used as an illuminant, whereas liquid fuel cannot. There is, therefore, no temptation presented by the latter to illicit abstraction of an occasional bottle for private use.

With small centrifugal pumps which necessarily run at a very high speed and have small driving pulleys, belting gives a good deal of trouble and neither leather nor cotton belts last very long. The latest belt tried at Melrosapuram is made of chrome leather and was manufactured in the Madras School of Arts. When first brought into use it stretched a great deal and required very frequently taking up, but now, that the initial stretch has been removed, it runs very satisfactorily and will probably prove much more durable than the ordinary belts on account of the greater pliability of the leather.

In this note it is not proposed to give any detailed account of the agricultural work done at Melrosapuram since the establishment of the pumping plant. The conditions under which Mr. Andrew was compelled to manage the place were not conducive to obtaining highly efficient results. His residence was more than seven miles away and the farm at Melrosapuram could but receive a limited amount of attention from him. For part of the time his assistant the Rev. Mr. Jeevaratnam was resident on the spot and able to get work pushed on but in 1904 he was transferred to Chingleput and is only able to visit Melrosapuram two or three times a week. Consequently the results of farming at Melrosapuram are not altogether satisfactory from an agricultural point of view; but they are of considerable interest as showing what may be done, under comparatively unfavourable circumstances, to increase the yield of the soil by the application of water and manure.

The land under cultivation was mainly worked by the Mission with hired labour and there was in addition be-

longing to the Mission an area of 3·41 acres planted with various fruit trees several years previously. Though little labour was expended upon them, they received a liberal supply of water and the yield of produce very greatly increased. An area of 2½ acres was divided up between the settlers at Melrosapuram and constituted backyards to their houses and in addition some of these settlers rented small patches of land from the Mission which they cultivated. From frequent personal inspection of the settlement I am inclined to think that the best cultivation was in the backyards and there is no doubt whatever that this land yielded a very high return per acre. As most of the produce was consumed by the tenants, no accounts either of labour or of receipts were procurable and it is only possible to form an approximate estimate of the value of the produce grown on these lands.

Tables C and D.

The following table shows the gross value of the produce of the land of the settlement during the last four years :—

1901–02	..	Rs.	280	No pump.
1902–03	..	,,	657	Pump working.
1903–04	..	,,	1,284	Pump working and intensive cultivation.
1904–05	..	,,	2,049	Pump working and intensive cultivation.

The expenditure, including an adequate allowance for interest and depreciation of the pump, has been as follows during the same years :—

	Rs.	Loss.	Rs.
1901–02	249	,,	..
1902–03	986	,,	336
1903–04	2,015	,,	731
1904–05	2,278	,,	229

From the details given in Tables A and B of Appendix II it will be seen that the cost of labour has been extremely high amounting to as much as Rs. 46-8-0 per acre in 1903-1904 and Rs. 70-8-0 in 1904-1905. This includes certain non-recurring work, but even when allowance is made for that, it is evident that the labour has been very expensive. Whilst in the statement of receipts credit has been taken for the produce of the tenant's land and back gardens, no corresponding debit has been made on account of the labour employed on these lands in the statement of expenditure. The accounts, therefore, are of no value as a statement of profit and loss.

The issues raised at Melrosapuram by these experiments are two and they should be clearly distinguished from one another. The results obtained so far show that, with adequate pumping-power, it is possible to improve the water-supply and to cultivate a very considerable tract of land under a single well. Figures have been obtained which show accurately the actual cost of pumping and although they are very high yet they are valuable as showing what has actually been done and as indicating clearly the direction in which improvement must be effected.

As regards the determination of the duty of water, the data collected so far only afford approximate information as to the total quantity of water which was used on the land at Melrosapuram. The record shows the number of hours the engine was at work in each month and the levels from which water was pumped, from which it would be possible to calculate fairly accurately the quantity of water raised if the discharge of the pump at each level was accu-

rately known. Unfortunately, owing to a variety of minor causes, the efficiency of the engine was not uniform. The driver generally cleaned it only when bad running showed the necessity for such a measure and a great deal of trouble seems to have been experienced with belting owing to the attempt to run with belts which ought to have been discarded as worn out. It has been assumed that the average discharge of the pump was 1,440 cubic feet per hour up to the time it was damaged at the beginning of April 1904 and that after that date it did not average more than 1,280 cubic feet per hour. It is scarcely probable that there is an error in this assumption to the extent of 2 per cent. either one way or the other, and the data collected would be extremely valuable if any account had been kept of the use made of the water. This unfortunately has not been done and the only information which can be furnished at present relates to the average duty of water for the whole farm. From Table J of Appendix II it will be seen that in 1903–1904 the minimum duty occurred in June and was 208 acres per cubic foot per second, whilst in 1904–1905 the largest quantity of water was supplied to the land in November when the duty amounted to 137 acres per cubic foot per second.

It must be remembered that this note is but an interim view of the work done up to date and must in no sense be taken as a final statement of the results which are likely to be achieved. Both in pumping and agriculture every one connected with Melrosapuram has had to gain experience and on the engineering side this has been possible with greater rapidity than on the agricultural where two

or three seasons will yet be required to enable the cultivation to be fully developed. It is not a small matter that during the last year the actual out of pocket expenses were met by the value of the crops raised and in the current year it is expected that the farm as a whole will pay its way with a clear margin for supervision after meeting all charges for interest and depreciation.

In judging of the work done at Melrosapuram it must be remembered that the Free Church of Scotland Mission regard the irrigation and agricultural experiments which have been in progress there as quite secondary to the social work of regenerating the Panchama community which was the original object with which the settlement was founded. It is not a small matter to have demonstrated that a radical change in the system of drawing water for irrigation for wells is practicable, but in the eyes of Mr. Andrew and of his co-adjutors the work of regenerating a fallen race is infinitely more important and Mr. Andrew may be accounted as exceedingly fortunate in being able in one scheme to combine plans both for the moral and the material advancement of the Panchama community.

APPENDIX I.

Table I.—*Measurement of inflow to well at Melrosapuram, 7th and 8th February 1903.*

Time in hours from commencement or cessation of pumping	Depth of water in well in feet.	Rise or fall of level of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0	3·42	1·75	4·30	540	...
1	5·17	1·25	5·80	385	...
2	6·42	1·00	6·92	308	...
3	7·42	0·91	7·87	307	...
4	8·33	4·00	10·33	203	...
10·78	12·33	5·08	9·79	...	1,880
1	7·25	3·42	5·54	...	1,465
2	3·83	2·83	2·42	...	1,440
3	1·00	0·67	0·67	...	1,435
3·25	·33	1·92	1·29	591	...
1	2·25	1·58	3·04	487	...
2	3·83	1·59	4·62	490	...
3	5·42	1·08	5·96	672	...
3·5	6·50	3·33	4·83	...	...
1	3·17	2·50	1·92	...	1,460
2	0·67	...	...	...	1,368
2·28	0·42	2·00	1·42	616	...
1	2·42	1·58	3·21	487	...
2	4·00	1·50	4·75	463	...
3	5·50	1·00	6·00	308	...
4	6·50				

Table II.—*Measurement of inflow to well at Melrosapuram, 28th February* 1903.

Time in hours from commencement or cessation of pumping.	Depth of water in well in feet.	Rise or fall of level of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0	0·0				
0·25	0·92	...	...	...	...
0·50	1·50	...	...	...	...
1·50	3·47	1·97	2·48	607	...
1·75	3·86	0·39	3·66	480	...
2·00	4·25	0·39	4·05	480	...
2·25	4·58	0·33	4·42	404	...
2·50	4·96	0·38	4·77	465	...
2·75	5·31	0·35	5·14	432	...
3·00	5·67	0·36	5·49	444	...
3·50	6·31	0·64	5·99	397	...

Table III.—*Measurement of inflow to well at Melrosapuram, 26th September* 1903.

Time in hours from commencement or cessation of pumping.	Depth of water in well in feet.	Rise or fall of level of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0	19·58	...	...	...	...
0·50	18·00	2·50	16·75	...	1,910
1·00	15·50	2·29	14·36	...	1,776
1·50	13·21	2·13	12·14	...	1,975
2·00	11·08	3·75	9·20	...	2,006
3·00	7·33	1·25	6·70	...	1,751
3·50	6·08	1·00	5·58	...	1,660
4·00	5·08	1·08	4·54	...	1,721
4·50	4·00	0·75	3·62	...	1,600
5·00	3·25	0·29	3·11	...	1,450
5·33	2·96	0·96	3·44	1,185	...
0·25	3·92	0·83	4·33	1,505	...
0·42	4·75	0·75	5·12	925	...
0·67	5·50	0·75	5·12	...	1,478
0·50	4·75	0·67	5·08	1,145	...
0·18	5·42	0·66	5·75	813	...
0·43	6·08	0·59	6·37	726	...
0·68	6·67				

TABLE IV.—*Measurement of inflow to well at Melrosapuram, 24th December* 1903.

Time in hours from commencement or cessation of pumping.	Depth of water in well in feet.	Rise or fall of level of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0·00	10·96	1·20	8·95	...	1,564
0·50	9·55	1·05	7·82	...	1,606
1·00	8·35	1·00	6·80	...	1,572
1·50	7·30	0·95	5·82	...	1,552
2·00	6·30	0·70	5·00	...	1,456
2·50	5·35	1·20	4·05	...	1,830
3·00	4·65	1·00	2·95	...	1,468
3·50	3·45	1·00	1·95	...	1,532
4·50	2·45	0·85	1·02	...	1,558
5·00	1·45	0·20	...	...	...
6·50	0·60	2·30	1·55	1,416	...
6·67	0·40	1·60	3·50	986	...
0·50	2·70	1·65	5·12	1,016	...
1·00	4·30	1·20	6·55	813	...
1·50	5·95	2·15	8·22	1,555	...
2·00	7·15	1·10	9·85	744	...
2·30	9·30	0·75	10·78	507	...
3·00	10·40	1·05	11·67	710	...
3·50	11·15	0·70	12·55	473	...
4·00	12·20	...	...	...	...
4·50	12·90	0·90	13·35	305	...
5·50	13·80	0·60	14·10	203	...
6·50	14·40	0·77	14·79	261	...
7·50	15·17	1·48	15·91	480	...
8·50	16·65	0·65	16·97	220	...
9·50	17·30	0·70	17·65	237	...
10·50	18·00				

TABLE V.—*Measurement of inflow to well at Melrosapuram, 6th and 7th April* 1904.

Time in hours from commencement or cessation of pumping.	Depth of water in well in feet.	Rise or fall of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0	2·25	1·75	3·12	539	
1	4·00	2·00	5·00	616	
2	6·00	1·80	6·90	608	
3	7·80	1·25	8·42	422	
4	9·05	0·95	9·52	328	
5	10·00	0·70	10·35	237	
6	10·70	0·75	11·07	253	
7	11·45	0·55	11·72	186	
8	12·00	0·50	12·25	169	
9	12·50	0·50	12·75	169	
10	13·00	0·33	13·16	112	
11	13·33	0·30	13·48	102	
12	13·63	0·29	13·78	98	
13	13·92	0·41	14·12	138	
14	14·33	0·27	14·47	91	
15	14·60	0·10			
18	14·70	0·30	15·05	25	
20	15·00	0·50			
27	15·50				

TABLE VI.—*Measurement of inflow to well at Melrosapuram, 7th April* 1905.

Time in hours from commencement or cessation of pumping.	Depth of water in well in feet.	Rise or fall of water in well in feet.	Mean depth of water in well in feet.	Percolation in cubic feet per hour.	Discharge of pump in cubic feet per hour.
0	0·55	0·13	0·62	454	
0·25	0·68	0·10	0·73	354	
0·50	0·78	0·10	0·83	354	
0·75	0·88	0·13	0·95	454	
1·00	1·01	0·19	1·11	327	
1·50	1·20	0·15	1·27	265	
2·00	1·35	0·20	1·45	353	
2·50	1·55	0·15	1·62	265	
3·00	1·70	0·12	1·76	212	
3·50	1·82	0·18	1·91	318	
4·00	2·00	0·13	2·06	230	
4·50	2·13				

On this day the engine and pump in 57 minutes lowered the water in the well from 2 feet to 1 foot. In 180 minutes percolation restored the water to the same level. By actual measurement it was ascertained that the average discharge of the pump was 24 cubic feet per minute. Then let $x =$ storage capacity of well between 1 foot and 2 feet levels and let $y =$ the rate of inflow.

$$x + 57y = 24 \times 57 = 1{,}368$$
$$x = 180y$$
$$\therefore 237y = 1{,}368$$
$$y = 5{,}77$$
$$x = 1{,}039$$

Table VII.—*Gwynne's Centrifugal Pump.*

(Approximately constant speed.)

Lift in feet.	Discharge in cubic feet per hour.	Water horse power.
17·1	1,795	0·968
17·8	1,780	1·000
21·5	1,532	1·040
23·35	1,384	1·020
24·00	1,384	1·049
25·75	1,285	1·044
27·6	1,285	1·120
29·0	1,245	1·138
19	1,880	1·128
21	1,724	1·143
23	1,600	1·162
25	1,500	1·153
27	1,416	1·206
29	1,344	1·230

Table VIII.—*Worthington Centrifugal Pump.*

Speed.	Lift.	Discharge in cubic feet per hour.	Water horse power.
625	22·7	998	0·72
635	23·2	1,200	0·88
660	24·7	1,517	1·18
670	26·3	1,459	1·24
675	25·6	1,709	1·38
696	28·4	1,536	1·377
724	28·4	1,709	1·533
742	28·3	1,958	1·733
747	28·9	1,977	1·777

APPENDIX II.

Table A.—*General Statement of Charges incurred at Melrosapuram, from April* 1903 *to March* 1904.

	RS.	A.	P.	RS.	A.	P.
(A) *Engine and Pump*—						
Engine oil	303	8	0			
Driver's wages ..	60	0	0			
Repairs, etc.	83	0	4			
Interest and depreciation at 12½ per cent. on Rs. 2,400 ..	300	0	0			
				746	8	4
(B) *Cultivation*—						
Labour	541	7	1			
Seed	328	0	0			
Manure and silt ..	380	10	7			
				1,250	1	8
(C) *Land-tax*				19	0	10
Total ..				2,015	10	10

Note.—The area under cultivation was 20·54 acres, but the above accounts as regards labour charges only apply to 11·63 acres. The remaining area includes the Mission garden of 3·41 acres, where the fruit trees required practically no attention, the backyards of the settlers amounting to 2·50 acres for which no labour accounts have been kept and 3 acres of land sublet to tenants from whom no accounts can be obtained.

Table B.—*General Statement of Charges incurred at Melrosapuram, from April* 1904 *to March* 1905.

	RS.	A.	P.	RS.	A.	P.
(A) *Engine and Pump*—						
Engine oil	545	12	8			
Driver's wages ..	70	0	0			
Repairs, etc.	172	5	2			
Interest and depreciation at $12\frac{1}{2}$ per cent. on Rs. 2,400 ..	300	0	0			
				1,088	1	10
(B) *Cultivation*—						
Labour	797	8	1			
Seed	174	2	1			
Manure and silt ..	201	14	9			
				1,173	8	11
(C) *Land tax*				15	14	3
Total ..				2,277	9	0

Note.—The area under cultivation was 18·29 acres, but the above accounts as regards labour charges only apply to 11·32 acres. The remaining area includes the Mission garden of 3·41 acres where the fruit trees required practically no attention, the backyards of the settlers amounting to 2·50 acres for which no labour accounts have been kept and 1·06 acres of land sublet to tenants from whom no accounts can be obtained.

TABLE C.—*General Statement of Income derived at Melrosapuram, from April* 1903 *to March* 1904.

Area.	Crop.	Total value.			Value per acre.
ACS.		RS.	A.	P.	RS.
5·86	Plantains ..	593	3	6	101
0·48	Sugarcane ..	203	15	9	425
3·41	Gardens ..	116	13	11	34
2·50	Produce of the backyards ..	300	0	0	120
0·65	Minor products, such as yams, ragi, etc., and miscellaneous receipts ..	70	11	8	..
(*a*) 4·64	Saffron	....			[*Vide* foot-note (*b*)]
Total .. 17·54		1,284	12	10	

Note.—(*a*) This area excludes 3 acres of land sublet to tenant from whom no accounts can be obtained.

(*b*) The receipts from saffron were all realized during, and hence included in the accounts of 1904–1905.

Table D.—*General Statement of Income derived at Melrosapuram, from April* 1904 *to March* 1905.

Area.	Crop.	Total value. RS.	A.	P.	Value per acre. RS.
ACS.					
7·98	Plantains	626	12	6	79
3·34	Sugarcane	524	14	2	157
3·41	Gardens	227	0	8	67
2·50	Produce of the backyards.	375	0	0	150
(*a*) 4·64	Saffron	142	13	0	31
(*b*) ——	Minor produce and miscellaneous receipts ...	152	6	8	...
Total. 17·23		2,048	15	0	

Note.—(*a*) This crop was grown in 1903–1904 (*vide* Table C.)
(*b*) This extent excludes the saffron area of 4·64 acres and the area of 1·06 acres sublet to tenants from whom no accounts can be obtained.

Table E.—*Record of pumping operations at Melrosapuram, for the year* 1903–1904.

Month.	Number of times the engine was started.	Number of hours the engine ran. HRS.	MTS.
1903.			
April	58	140	0
May	38	89	13
June	57	112	52
July	44	90	55
August	28	53	20
September	8	18	35
October	6	19	20
November	...	...	
December	6	26	8
1904.			
January	...	...	
February	45	137	50
March	44	142	40
Total ...	334	830	53

Table F.—*Record of pumping operations at Melrosapuram, for the year* 1904–1905.

Month.	Number of times the engine was started.	Number of hours the engine ran. HRS.	MTS.
1904.			
April	39	135	20
May	46	154	45
June	48	156	25
July	50	216	0
August	48	226	40
September...	42	147	25
October	36	232	10
November	40	271	25
December	38	143	29
1905.			
January	58	143	22
February	68	133	59
March	55	112	12
Total ...	568	2,073	12

Table G.—*Table showing the kind, amount and price of oil used for the Engine at Melrosapuram, from April* 1903 *to March* 1904.

Month.	Amount of oil in gallons. Kerosine.	Amount of oil in gallons. Liquid fuel.	Cost of oil. Kerosine. RS. A. P.	Cost of oil. Liquid fuel. RS. A. P.
1903.				
April	160	...	67 8 0	...
May	80	...	32 8 0	...
June	160	...	61 4 0	...
July	80	...	32 8 0	...
September	80	...	30 0 0	...
October	...	34	...	6 2 0
1904.				
February	192	...	73 10 0	...
Total ...	752	34	297 6 0	6 2 0

Total number of gallons of oil 786

Total cost of oil ... ... RS. 303 A. 8 P. 0

TABLE H.—*Table showing the kind, amount and price of oil used for the Engine at Melrosapuram, from April* 1904 *to March* 1905.

Month.	Amount of oil in gallons.		Cost.					
	Kerosine.	Liquid fuel.	Kerosine.			Liquid fuel.		
1904.			RS.	A.	P.	RS.	A.	P.
April	80	32	38	12	0	6	0	0
May	112	84	49	6	9	15	12	0
June	173	...	74	3	4	...		
July	...	60	...			13	4	0
August	148	60	59	3	0	12	8	0
September	58	80	24	0	6	16	13	0
October	60	80	22	15	6	15	0	0
November	66	120	27	6	6	21	0	0
December	152	...	60	0	0	...		
1905.								
January	46	132	18	11	2	27	10	6
February	48	...	19	14	5	...		
March	20	80	8	4	0	15	0	0
Total ...	963	728	402	13	2	142	15	6

Total number of gallons of oil	1,691		
	RS.	A.	P.
Total cost of oil	545	12	8

TABLE J.

Month.	Number of hours engine was at work.	Gallons of water lifted.	Rainfall.			Duty of water.	
			Melrosapuram.	Madras.	Chingleput.	Gallons per acre.	Acres per cusec.
1903.							
April.	140	1,260,000	*Nil.*	*Nil.*	*Nil.*	327	264
May.	89	801,000	3·10	5·32	8·01	201	429
June.	183	1,647,000	0·70	1·46	1·00	428	202
July.	91	819,000	4·01	3·80	3·64	206	420
August.	53	477,000	3·82	6·45	6·25	120	721
September.	19	171,000	5·58	9·66	7·39	44	1,942
October.	19	171,000	2·92	8·84	5·57	43	2,007
November.	*Nil.*	*Nil.*	6·65	17·74	15·07	*Nil.*	...
December.	26	234,000	10·18	18·55	20·29	58	1,475
1904.							
January.	*Nil.*	*Nil.*	0·25	2·10	1·62	*Nil.*	...
February.	138	1,242,000	*Nil.*	*Nil.*	*Nil.*	334	259
March.	143	1,287,000	*Nil.*	*Nil.*	*Nil.*	323	267
April.	135	1,080,000	*Nil.*	*Nil.*	*Nil.*	315	274
May.	155	1,240,000	0·53	0·92	1·08	350	247
June.	156	1,248,000	0·37	0·58	0·76	364	237
July.	216	1,728,000	2·93	5·21	4·02	487	177
August.	226	1,808,000	1·05	2·55	2·06	510	169
September.	147	1,176,000	1·27	3·51	2·55	343	252
October.	232	1,856,000	1·30	2·33	5·30	524	165
November.	271	2,168,000	0·78	0·20	0·67	632	137
December.	143	1,144,000	1·07	3·34	2·63	323	268
1905.							
January.	144	1,152,000	0·17	1·92	0·35	325	266
February.	134	1,072,000	*Nil.*	0·31	*Nil.*	334	258
March.	112	896,000	...	0·85	0·65	252	342

Note.—It is assumed that the average discharge of the pump during 1903-1904 is 1,440 cubic feet per hour and the area under cultivation was 20·54 acres. In 1904-1905 the pump discharge is assumed to be 1,280 cubic feet per hour and the area under cultivation was 18·29 acres. Comparison of the rainfall data of Melrosapuram with Madras and Chingleput indicate that the records of the former are valueless.

IRRIGATION BY ARTESIAN WELLS.*

——:o:——

IN an article contributed to *The Madras Mail* in October last, I wrote :—" The wells from which Mr. Panduranga Moodelliar is pumping water near Cuddalore derive their water-supply from beds of sand near the surface. He has started with one well 12 ft. in diameter and has sunk alongside it a second well 20 ft. in diameter and now he proposes to sink a third well so as to obtain an increased area of percolation and a large storage capacity for water. His wells are already over 30 ft. deep and further progress is barred by the fact that they now rest on a bed of clay. Under this bed of clay, which has been proved to have a thickness of more than 50 ft., it is not at all improbable that water-bearing sands or gravels may be met with, and it is quite possible that by sinking the bore hole to a sufficient depth we might obtain an artesian or sub-artesian supply of considerable volume."

It is interesting now to be able to report that Mr. Panduranga Moodelliar has employed some well-borers from Pondicherry to test the truth of this conjecture, with the result that it has proved correct. At a depth of 84 ft. from the surface he struck artesian water which rose in his well to within 14 ft. of the level of the ground. At first the supply was very copious and a considerable volume

* *The Madras Mail*, 19th April, 1906.

of sand and mud was brought up with it, but after a few days the supply decreased and the water came up clear. Last week I visited the well and measured the discharge, the top of the artesian tube being 28 ft. below the ground level. The internal diameter of the tube is 7″ and the discharge amounted to 140 gallons per minute or, say, 200,000 gallons per day, which is probably sufficient for the irrigation of 50 acres of garden produce. During the day time, while the engine and pump are at work, the water is kept down in the well so that the mouth of the tube is free, but as soon as pumping ceases the water begins to steadily rise in the wells and the static level, or the level to which the water rises when none is drawn off, is 14 ft. below the surface of the ground. This is, therefore, what is usually termed a sub-artesian supply. As Mr. Panduranga Moodelliar's engine and pump can easily deal with a discharge of 300 gallons per minute, I have advised him to put down two more 7″ boreholes in his larger well, and this he has agreed to do. As the well is already 31 ft. deep at the place where the borings will be started, it will only be necessary to carry them down slightly over 50 ft., and the cost of doing this will be about Rs. 100 for each borehole. It is probable that when this is done an assured supply of over 300 gallons per minute will be obtained, which, with 10 hours pumping per day, will be more than sufficient to command the 60 acres of land which Mr. Panduranga Moodelliar owns in that neighbourhood.

As already stated, the well-boring operations were carried out by men from Pondicherry, and from them we learnt that a very large number of artesian wells are in

use in the country south of Pondicherry for irrigation of paddy crops. It is, I believe, fairly well known that there are a number of artesian wells in Pondicherry, and the general impression regarding these sources of water-supply is fairly accurately stated in the Report of the Irrigation Commission, in which the Commissioners mention that they have received information regarding 11 artesian wells in Pondicherry yielding a total supply of $5\frac{1}{2}$ cusecs. No allusion is made to any irrigation under these wells and I think the general impression, which I have hitherto shared, is that the artesian water-supply in Pondicherry and its neighbourhood is not of much importance. That this is erroneous will be seen from the following facts which I gathered during a brief visit to the French territory in company with Mr. Panduranga Moodelliar. The road from Cuddalore to Pondicherry crosses the Ponniar river about a mile and a half out, and almost immediately begins to wind its way through alternate French and British villages. For some miles on either side of the road the country at this time of the year is dry and barren, but almost immediately after passing the Customs House, which is six or seven miles from Cuddalore, patches of bright green paddy are to be seen, and beyond the Kilinjar river the greater part of the land on both sides of the road is under cultivation and presents a strange contrast to the burnt-up fields which here and there intervene and which can be seen all along the road in the far distance. Leaving the main road beyond the Kilinjar river we inspected a number of wells in various villages, and as we were accompanied by two well-boring

maistries and by the owners of most of these wells, we were able to get fairly accurate information regarding them. All the wells are bored the same diameter, *viz.*: 7″, and in depth they vary from 150 to 250 ft. The tubing is made of sheet iron riveted together in lengths of 4 ft. and the ryots measure the depth of a well by the number of tubes employed. One of the best wells we saw had been sunk to a depth of 184 ft. and apparently yielded a supply of about half a cubic ft. per second. The irrigation under it was said to be 20 acres, and the cost of putting down the well Rs. 300. The water in many of the wells appears to contain salts of iron as the channels flowing away from them bore evidence of this. In one village, Pudukuppum, there were 10 wells, and in another village, Kilinji-kuppum, there were 12 wells, the total area under irrigation in these two villages being 150 acres, or an average of about 7 acres per well. One of the well-boring maistries, Manicka Gownden by name, informed me that he had learnt the trade from a man brought to Pondicherry by the French Government, and that during the last 10 or 12 years he had sunk between 200 and 300 wells, whilst the other maistry claimed to have put down independently 210 wells. These figures may or may not be correct, but I am quite certain that there are many hundreds of wells to the south of Pondicherry and that probably more than a thousand acres are under irrigation from them. I was told there are a considerable number of people engaged in well-boring and that about 25 sets of well-boring apparatus are in use. No attempt has been made anywhere except in the well belong-

ing to the Anglo-French Textile Company at Pondicherry to increase the natural flow of the wells, and the result is that most of them yield only a comparatively small quantity of water. It would seem that the greater number of wells are in French territory, but there are also a considerable number in the British villages scattered throughout the country between the Ponniar and the Kilinjar Rivers.

One or two attempts to obtain artesian water have, I believe, been made in Cuddalore ; but they ended in failure, or supposed failure, because no water rose above the level of the ground. Mr. Panduranga Moodelliar's boring on the banks of the Ponniar River shows that the bed of artesian water is of enormously greater extent than has hitherto been supposed, but that in its southern extension the pressure is not sufficient to bring the water above the level of the ground. Although the number of boreholes which have been put down is very considerable, the quantity of water drawn from these sands is by no means large, and it is probable, nay practically certain, that by pumping it could be enormously increased. The villagers told me that in the rainy season the wells yield rather more water than in the hot weather, but that there is no great difference in the yield throughout the year.

The value of this water-supply depends very much more upon the fact that it is constant throughout the year than upon its actual volume. But, unfortunately, the poverty and indolence of the ryots precludes them from making any use of its perennial character. Usually, where artesian water is available, two crops of paddy are grown and the

land is heavily manured with castor cake. There seems to be scarcely any doubt that, if a number of small pumping stations were installed throughout this tract of country, several thousand acres might be brought under sugar-cane cultivation and the wealth of the people enormously increased. There are no large landholders, and individual ryots are quite unable to undertake the operations necessary to fully utilise the value of these stores of subterranean water.

When a well yields more water than the owner requires for the irrigation of his land he sells the rest to his neighbours, taking one-third of the gross produce of the land in return for the water. Possibly some such system as this might be adopted on a large scale, but it would be better if it were undertaken by private enterprise than through any Government agency, as not only would it be necessary to find capital for the pumping machinery but also for advances to the ryots to enable them to undertake improved methods of cultivation. Where water is supplied to the ryots by pumping, the cost is naturally greater than when it comes from a tank or channel, though it is always very much less than that which the ryot incurs when he bales out water from a well by means of a picottah or mhote. Nevertheless, he is extremely unwilling to pay a water rate which may amount to Rs. 15 or Rs. 20 per acre per annum, although this is very much less than he is actually paying when he employs coolies or cattle to lift water for him. In the one case he has to pay money down, and the ryot dislikes parting with money, whilst in the

other the payment is made in kind and is usually a part of the produce of the land itself. The introduction of the *varam* system seems to be the most likely way in which it will be practicable to bring to the aid of the ryot capital which would be freely available before ready means of applying it can be devised. Sugarcane cultivation offers the most favourable field for experiments in this direction, and so far as I am able to judge, the country round Cuddalore possesses unusual facilities for the growth of such a crop.

The cretaceous deposits of Pondicherry are well known to geologists and have been the subject of several learned memoirs, but the artesian water-supply derivable presumably from the extension of these beds has not received the attention which it deserves. I have no information as to the position or the area of the out-crop of these water-bearing sands, yet from an economic point of view it is important that these should be thoroughly investigated, so that some estimate may be formed as to the capacity of the subterranean reservoir.

IRRIGATION BY PUMPING IN THE UNITED STATES.*

FOR the last three years I have been in charge of the experimental irrigation pumping plants in the South of India, the first of which was established at Melrosapuram in 1902, and as there is a prospect of the number increasing very rapidly in the immediate future, I thought it was desirable that first-hand information should be obtained regarding similar work in the United States, where during the last few years, they have been installed on a larger scale than anywhere else in the world. With the sanction of the Secretary of State for India, I visited America in the autumn of last year and accordingly in the course of my tour spent some time in the districts of the States of Utah and California where there are large areas of irrigation dependent upon water pumped from low levels to a height sufficient to command the land.

The total area of the United States is very nearly three million square miles, and of this area not less than one and a quarter million square miles between the Mississippi river and the Pacific Ocean is so situated that cultivation without irrigation is either extremely precarious or absolutely impossible. Till the passing of the National Reclamation Act by Congress in June 1902, which authorizes the construction of irrigation canals and reservoirs by the

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* *The Indian Review*, May 1905.

Federal Government, the development of irrigation has been entirely left to private enterprise. The earliest settlers were the Spaniards who came from Mexico up the valley of the Rio Grande river and found the Indians of that region, "watering the thirsty soil, as their forefathers had done for unnumbered generations before them and as their descendants are doing to-day." These pioneers of European civilization recalled the wonderful fertility of the irrigated fields in the south of Spain and the colonies which they established, in what are now the territories of Arizona and New Mexico, imitated and to some extent improved upon the primitive practices of the red-skinned savages. Later, in the middle of the eighteenth century the mission fathers of Mexico established a chain of stations along the Pacific Coast from San Diego to San Francisco and to them the credit is due of introducing the methods of irrigation practised in Spain.

On the East Coast, in the Carolinas and Georgia, the eighteenth century witnessed the gradual growth of rice cultivation on low and marshy lands bordering on tidal rivers. At high tides the fresh water was backed up the rivers and flooded the rice fields, at low tides the water receded and the fields could be drained. From small beginnings the rice planting became an important industry and in the years preceding the great Civil War 80,000 acres yielded annually nearly 50,000 tons of cleaned rice. The ruin caused by the war and the changed labour conditions consequent upon the abolition of slavery led to the abandonment of many of the plantations so that for the

last forty years the production of Carolina rice has been less than half what it formerly was.

Within, however, the last ten years along the shores of the Gulf of Mexico in the States of Louisiana and Texas, rice growing has been taken up on a very extensive scale, the necessary water being obtained by pumping from the sluggish streams or bayous which cary the drainage of the coast lands to the sea through a wide belt of marshy littoral. Nearly 300 pumping stations supply water to 610,000 acres, which yielded last year about 400,000 tons of cleaned rice. Sixty six rice mills are in operation and it is computed that fully one crore of rupees has been invested in the industry. It would be difficult to find a more characteristic example of modern American enterprise in agricultural matters.

In California and the arid States of the west the early efforts of the Spanish settlers and monks supplied their own local requirements and ended there. The time was not ripe for the development of the country. There was no population to feed and no means of exporting surplus produce. Modern American irrigation owes its origin in the first instance to the Mormon community who 55 years ago sought a safe refuge from persecution beyond the Rocky Mountains in the arid plains of Utah and secondly to the necessity of furnishing supplies for the mining camps which followed the discovery of the mineral wealth of California and Colorado. The trans-continental railways opened up the country and gave the fruit growers and stock-raisers of the west access to the Eastern markets in which there is an enormous demand for their produce.

Yet another impulse to the extension of irrigation was found in the semi-arid regions on the eastern slopes of the Rocky Mountains, where frequent periods of drought or scanty rainfall have compelled farmers to seek in the streams coming from the mountains or in the gravel beds beneath the soil for the water without which their crops were withering, their cattle dying and they themselves were being reduced to penury. The success which attended the earlier efforts of individuals led to the formation of joint-stock companies, who undertook the construction of hydraulic works on a considerable scale to render large volumes of water available for the irrigation of extensive tracts of land. Many mistakes were made through inexperience and lack of knowledge, the cost of works was frequently under-estimated and not a few of the undertakings ended disastrously for the original shareholders. Still, on the whole, private effort has proved fully equal to the occasion and during the last 35 years at least 60 crores of rupees have been expended in bringing under irrigation ten million acres of land. Measured by the rise in value of the land or by the annual value of the crops, the investment has been extremely successful ; whilst the engineering works, as an adaptation of means to an end, as a display of fertility of resource and boldness of conception, are of more than ordinary interest.

After India the United States have now a larger irrigated area than any other country in the world and as yet they are but the beginning of things. It has been recognized that there are limits to the possibilities of develop

ment by private enterprise so the Federal Government has taken up the work and has already provided nine crores of rupees for the great projects now being investigated. Previous to this the scientific study of irrigation problems was taken up both by the Department of Agriculture and by the Geological Survey and the valuable series of reports which they have been issued, have provided reliable data upon which engineers could base their designs and legislators frame adequate laws for the protection of water rights.

Compared with India the conditions in the States are in almost every respect diametrically opposite. Everything has been left to private individuals and they have had a perfectly free hand in every way, there were no vested interests to contend with, capital was abundant and readily forthcoming, labour was very expensive but timber fairly cheap, the farmers are educated and enterprising, for live stock there is an indefinite market and the products of orchards and gardens realize high, and often, fancy prices. The effects produced by these conditions are clearly visible. No large or comprehensive projects have been carried out, present necessities and not future prospects have controlled the situation, conflicting interests have grown up, involving much litigation and frequent scenes of lawlessness. The paramount consideration was an immediate return on the capital outlay and in the face of adverse circumstances it has exercised a dominating influence over the character of the engineering. Problems have been tackled with a boldness which in some cases verges on recklessness and much of the work will have to be done over again. There is no doubt that the general policy was right but it was a tempo-

rary one and there is abundant evidence that a change is in progress in the direction of a demand for more solid construction and hydraulic works of a more permanent character.

When once the value of irrigation was demonstrated, it was but natural that every available source of water-supply should be examined and the prospects of making successful use of it carefully investigated. Farmers who had no hope of obtaining a gravity supply delivered on to their land turned their attention to the subterranean waters and from wells sunk to the water bearing beds soon found it was practicable to obtain sufficient for a patch of alfalfa or a vegetable garden which proved of immense value in seasons of deficient rainfall. To raise the water above the level of the ground windmills were freely resorted to and in the long run have proved convenient sources of power when the quantity required is not large and no great storage capacity is needed to tide over periods of calm weather. Hundreds of thousands of windmills are now in use for pumping water in the United States but only a very small percentage of them are doing much beyond supplying domestic requirements, watering stock and irrigating small fruit or vegetable-gardens. Where irrigation from wells is in vogue, the water-supply is invariably derived from beds of sand and gravel in which it frequently was found under artesian pressure sufficient to cause the water to flow up the bore holes above the level of the ground. In many cases this happy condition of affairs still prevails and there is a considerable area of land watered by such artesian wells but in most instances the number of bore holes tap-

ping the water bearing strata is so great that the pressure has fallen very considerably and the water now has to be raised by powerful engines and pumps.

Apart from windmills which are used to a not inconsiderable extent for irrigation in the States of Kansas and Nebraska, irrigation by pumping is most largely developed in California, Utah and Colorado and in the rice growing districts of Texas and Louisiana. The pumps employed are mostly of the centrifugal type, with either vertical or horizontal spindles, and for motive power practically every kind of modern prime mover has been tried ; whilst in California the system of lifting water by compressed air is in use and apparently with success notwithstanding the waste of energy which must necessarily occur when such a medium for transmitting power is employed.

Compared with what is known about the yield of water from wells in India those used for irrigation in America give very large supplies. Few, to which pumps are attached, yield less than half a million gallons per day and many of them several times that quantity. In consequence the units of power are very much larger than we can hope to install here, the range being usually from 20 to 60 H. P. Where the water-supply is derived from other sources than wells, as for instance from rivers or lakes, the pumping plants are very much larger and engines of several hundred horse-power are not uncommon. The depth from which it pays to pump water varies enormously being dependent on the value of the crops which can be grown, on the cost of motive power, which is itself a function of the price of fuel, and upon the duty of water for the crops under culti-

vation. Exceptional results are possible in districts where electric energy derived from water power is obtainable or where crude petroleum oil is found. In Utah State, at American Forks, electric power is sold at from 3·3 to 4·2 pies per horse-power per hour ; in California, at Bakersfield the price is 5·6 pies, at Mount Whitney 3·4 pies and at Riverside 9 pies. In Madras, oil engines will yield a brake horse-power for from 9 pies to As. 1, per hour using crude oil costing As. 3 per gallon whilst in Texas similar oil can be purchased at rates which fluctuate a good deal but probably do not average more than As. 1 per gallon. In California liquid fuel is equally cheap but it is unsuitable for oil engines on account of the large amount of asphaltum in its composition, and the distillate has, therefore, to be used and the price of this is practically As. 3 per gallon or about one-half the usual price in Madras. In the other arid States these favourable conditions do not prevail and the statement would be roughly accurate, that in respect to the cost of generating power they are no better off than we are in the Madras Presidency.

In the following notes I have attempted to summarize the vast mass of detailed information which was kindly placed at my disposal under convenient headings.

Windmills.—These are not largely used for irrigation work except in Kansas and Nebraska, where the winds are strong and reliable and the water bearing strata is no great depth from the surface. For domestic and other purposes requiring only small amounts of power the American windmill is used in enormous numbers, but for the sake of cheapness they are too lightly constructed and

can only work in moderate winds. In favourable situations windmills are probably the cheapest engines for pumping water available but, till the load is automatically adjusted to the velocity of the wind and in the proper proportion, the maximum yield of power will not be obtained from them. Windmills have been the subject of much study and investigation in the United Sates but the papers published by the Geological Survey contain discordant results and there is still a good deal of doubt on the subject of loading them so as to produce the best results.

In this *Review* for June 1903 under the title of "The Value of Windmills in India," I gave the results of experiments on an American windmill erected in the compound of the School of Arts, Madras, and more recently in an article in the *Madras Mail* of the 25th February, 1905, I have endeavoured to sum up the results of my observations in the United States. It is now under contemplation to carry out a further series of experiments with a Canadian windmill which gained the gold medal at the trials of windmills conducted by the Royal Agricultural Society of England in 1903. This windmill has been recently ordered and will be erected on the experimental farm at Melrosapuram.

Oil Engines.—Engines of small power which require a man to look after them are not at all economical in the States as the cost of labour is very high varying from Rs. 3 a day in the south to Rs. 7-8 in the west. Small oil engines are, therefore, not much used for pumping water but of sizes between 10 and 30 H. P. there are a considerable number in use, especially in places where they are only

required to run for a comparatively small number of days in the year. Oil engine fires are very common, so much so that the insurance rates are prohibitive. This is directly contrary to our experience in India as here we regard oil engines as perfectly safe motors and no serious accident has ever happened to disturb that belief. To facilitate starting oil engines, it is a common practice in America to begin with petrol and only when the engine is fairly at work to turn on the oil and there is no doubt that thereby a very serious extra fire risk is introduced.

Steam Engines.—For driving centrifugal pumps or air compressors, steam engines of all types are employed, from portable engines of 8 or 10 H.P. up to compound Corliss condensing engines capable of indicating 500 H.P. About these engines there is nothing particular to note and the interest in the matter lies with the fuels used for generating steam. Wood, coal and crude oil are used and the prices paid for them depend upon the locality and the facilities for transport. In the rice irrigation tracts of Texas oil costs from Rs. 1-8 to Rs. 2 per barrel of 35 English gallons, coal nearly Rs. 15 per ton and wood from Rs. 4-8 to Rs. 9 per cord of 128 c. ft. or roughly from Rs. 3 to Rs. 6 per ton. In the the Santa Clara Valley, California, distillate oil, roughly equivalent to bulk kerosine oil, costs $3\frac{1}{2}$ to As. 4 per gallon, further south at Bakersfield near the Kern Valley oil fields and round Los Angeles, in the neighbourhood of which there are also oil fields the price of both crude oil and distillate is much less, but liable to considerable fluctuations.

The comparative cost of pumping is conveniently expressed in terms of the cost per horse-power hour or per acre foot lifted one foot. An acre foot is the quantity of water which would cover one acre to a depth of one foot and is equal to 43,560 c. ft. or very approximately to a flow of one c. ft. per second for 12 hours. Experiments made with an 8 H. P. portable steam engine on a lift of 26 feet using coal costing Rs. 15 per ton gave the cost, per acre foot lifted one foot, at As. 5. An exactly similar rate was obtained with an oil engine on a lift of 33 feet using oil which cost As. 7 per gallon. A steam engine supplied with steam from boilers fired with wood at Rs. 12 per cord or, say, Rs. 9 per ton working on a lift of 45 feet raised one acre foot one foot high for As. 3-3. This is about the cost in Madras with small oil engines and centrifugal pumps, but it must be remembered that the above figures do not include any allowance for interest and depreciation.

Electro-Motors.—The low rates, quoted above, charged for electricity in Utah, and California have rendered it practicable to use this form of energy for driving centrifugal pumps lifting water for irrigation purposes. The current is in all cases generated by water power in the canyons of the neighbouring mountains and transmitted across country at pressures generally over 10,000 volts. The three-phase system is invariably employed and the current is transformed down at the pumping stations to 2,200 volts or to 2,500 volts and utilized in induction motors which have an efficiency of about 90 per cent. Except in the oil regions fuel is very dear in the Western States and there has been every induce-

ment to make as much as possible of the water power available. In California, the western slopes of the Sierras presented an unusually large number of favourable sites for the development of water power which have in many cases been taken up and the electric energy generated is raised to pressures as high as 33,000 volts rendering transmission possible to great distances with economy and efficiency. By linking up different systems power has been transmitted well over 200 miles and in the latest installation the pressures on the line have been raised to 50,000 volts. Electrically transmitted power can only be economically employed where the irrigation season lasts for at least six months and is consequently mainly to be seen in the Alfalfa fields and Orange gardens of the south.

The largest pumping station is in Utah State at Lehi where the river Jordan debouches from lake Utah. All the water passing down the river is diverted for irrigation and the level of the water in the lake is now so low that it has become necessary to lift the water from the lake into the river to obtain a supply adequate to the needs of the irrigation interests concerned.

Four centrifugal pumps with 54in. suction pipes have been installed and are driven through belting by four 100 H. P. Westinghouse induction motors running at 580 revolutions per minute. The speed of the pumps is 166 revolutions per minute. The power is supplied by the Utah County Light and Power Company of American Fork who have a water power generating station in the American Fork Canyon, distant about five miles from the town and about 11 miles from the Jordan pumping station at Lehi. The

three-phase system of transmission is in use at a pressure of 6,000 volts, which is reduced by means of three 170 K. W. transformers to 500 volts at the pumping station. The lift of the water varies with the level in the lake, the range being from 2 feet to 5 feet, and the discharge of each pump is 100 c. ft. per second. The price paid for power is Rs. 15 per horse-power of continuous supply per month. The efficiency of the motors is stated to be 75 per cent. and the total efficiency of the station including all losses when working on the maximum lift, 33 per cent. but at lower lifts the efficiency falls off. The irrigation season lasts six months and the pumps are at work 98 per cent. of that time. During the month of August 1904, the pumps were running 732½ hours out of 744. Nine hours was lost at the generating station and only 2½ hours at the pumping station. Storms and unfavourable meteorological conditions accounted for more than half the lost time. In the Utah valley lightning is often very intense and causes much damage to electrical installations, and it is generally considered better to shut down the station, when violent storms are in the neighbourhood, than run the risk of a transformer being burnt out. This pumping station cost about Rs. 1,50,000 but it can only be regarded as a temporary expedient whilst the whole question of irrigation from the Utah lake is under investigation by the Engineers of the Geological Survey. It is beyond the scope of this paper to enter into a discussion of the interesting problems which the irrigation in this valley has given rise to but pending their solution this electrically driven pumping plant enables 40,000 acres to be supplied with water at a

comparatively small cost. The duty of the water appears to be about 100 acres per c.ft. per second and as the pumping season lasts 180 days the quantity of water delivered to each acre amounts to about 3·6 acre feet. The working expenses are less than Rs. 1·50 per acre which is a very small charge on land the gross return from which a very low estimate places at over Rs. 100 per acre.

In the town of American Fork small electromotors of one-half H. P. are installed in a number of gardens to drive force pumps working on tube wells for domestic supply and for watering the lawns, shrubberies and orchards round the houses. The charge for a 12 hour day service is Rs. 3 per month. The Municipal Corporation derive part of their water-supply from an artesian well sunk to a depth of 400 feet, in which the water rises to within 22 feet of the ground level. A three H. P. Motor, working through a countershaft, drives an ordinary plunger pump, which raises the water into a tank from which it is delivered into the town mains. The total lift is about 36 feet and the charge for power supplied continuously day and night is Rs. 36 per month. The pump is placed at the bottom of a brick well about 6 feet in diameter, and the motor is above the ground. A small wooden shed covers the whole plant and once a day it is visited by a man to oil the bearings.

The generating station of the Power Company is situated in the American Fork Canyon 5 miles from the town. The plant consists of two 500 H. P. Pelton water wheels worked under a head of 290 feet and driving two 250 K. W. three-phase alternators at a tension of 6,000 volts.

In the town the pressure is reduced to 2,300 volts and each group of users is supplied at either 115 volts or 230 volts through small transformers fixed on the poles carrying the transmission line.

It was not possible to ascertain the extent to which electricity generated from water power has been made use of in California to raise water for irrigation. The Agricultural Department of the United States are collecting information on the subject, but their data are as yet very incomplete. The General Electric Company to whom I applied for assistance were kind enough to supply me with a list of thirteen large electrical supply companies, all of whom were furnishing power for pumping water. In consultation with the officers of the company, three irrigation stations were selected for inspection as typical of the others, and the following notes are compiled from information gathered locally.

The Bakersfield Power, Transit and Light Company has a generating station in a Canyon 16 miles from the town. The current, which is three-phase alternating, is transmitted at 10,000 volts and is used in the town for lighting purposes and by the tramway as well as for pumping water. For irrigation work 27 motors of from 30 to 40 H. P. are in use and for the water supply of the town a further 10 or 11 motors are employed. The water is found in beds of gravel about 60 feet below the ground and an abundant supply can be secured by sinking tube wells. The water is under sufficient pressure to rise to within 15 or 20 feet of the ground. At one of the town water supply stations two 12in. tube wells had been sunk to a depth of 100 feet

and the water was drawn from them by a centrifugal pump directly coupled to a three-phase induction motor. The pump was placed just above the wells and the suction pipe, 5in. in diameter terminated in branches, passing down the two wells. The pump was of the ordinary horizontal type and ran at 950 revolutions per minute, delivering 540 gallons of water per minute through a 6in. pipe under a total head of 110 feet. The pump was primed by running water into it from the delivery tank, both suction pipes being fitted with foot valves.

At the irrigation stations the arrangements were different as the lift was only to the level of the ground and did not in any case greatly exceed 30 feet. The electrical pumping stations all belong to the Power Company which supplies the water to the Kern County Land Company, who use it for the irrigation of Alfalfa, at the fixed rate of Rs. 4½ per cubic foot per second per day. A 30 H.P. motor will raise about 4½ cusecs, so that at the price charged the power realizes less than 6 pies per H. P. hour, and is almost exactly Rs. 21 per month. The pumping stations differ from one another not only in the size of pumps but also in the driving arrangements. In some, the pumps are of the horizontal type and driven by a belt from a horizontal motor, in others the pumps are vertical and the motor is directly connected to the pump by means of a vertical shaft. Under the conditions prevalent round Bakersfield there is not much to choose between the two methods of running but the opinion of the men in charge of the pumping work is in favour of the belt driven pumps. The belt is a less efficient means of carrying the power

from the motor to the pump than is the vertical shaft but the lubrication of the latter and the arrangements to resist the thrust due to the weight of the motor, pump and shaft, if not more liable to get out of order than belt-driven pumps, yet give rise to more serious accidents when anything does go wrong. The best evidence that can be adduced as to the ease and simplicity of working at these pumping stations is the fact that although they are 27 in number, they are all looked after by two young men who are paid Rs. 120 a month each in addition to their board. The wells are a considerable distance from one another and for these attendants to get round to each well once a day it is necessary to supply them with a horse and buggy. One of them accompanied me on my visit to several of the wells and I saw him start and stop the pumps without the least difficulty although but a few months before he had been a farm hand and had had no training either in mechanical or electrical engineering work. At the first station visited there were 4 tube wells of 12in. diameter sunk in a line, the distance between them being 10 feet. The pump was of the vertical type and was placed at the bottom of a timber pit about 16 feet below the ground, the suction pipe was horizontal with four branches dipping into the four wells. While pumping is going on the water sinks in the wells about 15 feet to produce the head necessary to maintain flow, so that the maximum lift is 31 feet. The delivery of water averages 4½ cusecs and the efficiency of the installation is 51 per cent. The motor was of the three-phase induction type rated at 30 H. P. and working under a pressure of 500 volts. The motor, pump, vertical

shaft and delivery pipe were carried by a steel frame work, square in plan, built of angles and bars and stiff enough to keep all the running parts in perfect alignment. The transformers, two in number, were in a separate shed and the connection with the high tension lines was made by a switch of simple construction placed outside, lightning-arresters were also provided, and an automatic device for switching out the motor should a temporary interruption at the current cause the pump to lose its suction vacuum.

Two other pumping stations were also visited in which horizontal belt driven pumps were in use. The belt drive was rather long and the belt was of very ample dimensions for the power to be transmitted. At one station the pump was primed by an ordinary force pump worked by hand and the operation of starting was distinctly laborious; at the other a small pump was driven through a countershaft by a belt off the pump spindle. The pumps were placed at a level considerably above that of the water in the wells and consequently the suction lift was much longer than in the case of the vertical pumps. In other respects the equipment of these stations was all of the same type.

The water delivered from each pump is run into a sump provided with fine screens to damp down the oscillations of the surface and then passed over a thin edged weir made from a sheet of steel plate. The weirs were usually 3 feet in length and the depth of water on the crest is measured by means of a Hook's Gauge, sliding with a micrometer screw on a graduated scale. In Bulletin No. 86 of the U. S. Department of Agriculture, discharge tables for such weirs have been computed and are found of great

value in measurements of water coming from channels or streams as well as from pumps. The extraordinarily high value which water for irrigation has risen to in recent years, has naturally led to more care in its measurement than is the practice in India and sharp edged weirs, especially those of the Cippoletti pattern, are very largely used in ordinary distribution work.

Ontario.—This is an irrigation colony entirely devoted to the cultivation of citrus fruits which was started by Messrs. Chaffey Bros., of Ontario, Canada and subsequently better known in connection with their irrigation schemes at Renmark in South Australia. When supplied with sufficient water the soil is extremely fertile and the conditions generally are peculiarly adapted to the growth of oranges and lemons for which there is a splendid market throughout the States and admirable transportation facilities. The quantity of water available for irrigation is limited and insufficient for the area of land which could be brought under cultivation; hence there has been every possible inducement to prevent waste of water and secure a high duty. The water supply is mainly derived by pumping from artesian or sub-artesian wells and it is conveyed to the fields in concrete pipes and the distributory channels are all of concrete. Furrow irrigation is invariably employed, and to avoid loss by evaporation, the water is sometimes carried down the furrows in pipes buried in the soil.

In Southern California flowing water is usually measured in "miners' inches," of which 50 are equal to one cusec and one miners' inch is considered sufficient for the irriga-

tion of 10 acres of land in Ontario, so that in ordinary terms the duty of water is 500 acres per cusec. The profits from citrus cultivation are very considerable and as land without water is valueless, water rights are extremely valuable. The capitalized value of 1 cusec, is about 3 lakhs of rupees equivalent to Rs. 15,000 per annum and equal to a water rate of Rs. 30 per acre, but water especially in seasons of scarcity is occasionally sold for much higher rates. One man who has more water than he needs is able to dispose of his surplus at the rate of Rs. 75 per day for 30 miners' inches or 0·6 cusecs, which is considered a sufficient watering for 10 acres. At Ontario the water supply is controlled by the San Antonio Water Company, the whole of the stock of which is held by the fruit growers in proportion to the area of land which they occupy. Each 10 acres is entitled to a continuous flow of one miners' inch, but as that is too small a stream for satisfactory irrigation, the custom is that each 10 acre plot gets a stream of 30 miners' inches for one complete day in the month. The electric generating station is situated in the San Antonio Canyon about 8 miles to the north of Ontario and the power is brought into the colony by overhead transmission lines at 10,000 volts pressure. The pumping plants make use of the greater part of the power but it is also employed in driving motors for miscellaneous work, for electric lighting, and for electrical cooking and heating. For these purposes the energy is retailed at from As. 1-3 to As. 1-6 per Kilowatt hour.

The wells from which the water is pumped for irrigation are situated in the debris at the foot of the San Gabriel

Mountains and are 8 in number. A description of one pumping station will apply to all. The power for all the wells is distributed at 2,200 volts from a central transformer station where the lines from the generating station bring in three-phase current at 10,000 volts. The wells are supplied, each with a 50 H. P. horizontal induction motor capable of working continuously at 60 H. P. output and the centrifugal pumps are of the vertical type and driven by quarter twist belts. At one station the pump was placed at the bottom of a timbered shaft 140 feet deep and immediately over a 12in. tube well sunk a further 460 feet. Owing partly to a long series of years of deficient rainfall and partly to the very heavy demands now made upon the stores of subterranean water, the level in the wells at North Ontario is steadily falling and nearly every year it is necessary to deepen the shafts and lower the pumps. For this reason the horizontal motors and belt drives are employed. At the time of my visit the depth of water flowing over the 3 feet measuring weir was 3·375in. indicating a discharge of 90 miners' inches or 1·80 cusecs on a lift of about 155 feet. The pumps which are two stage usually run for months without stopping but they are examined and oiled every four hours. Electrical power has been in use only some three years but previously both oil and steam engines were employed, pumping having been necessary for the last ten years.

The Gage Canal Company, Riverside.—This Company possess 13 groups of wells sunk on the banks of the Santa Ana river and a supply of about 1,500 miners' inches or 30 cusecs is obtained by pumping with power purchased from

the Edison Electric Companies' system, at the rate of As. 1 per K. W. hour. One group of wells was 6 in number, each a 7in. tube sunk 400 feet. The water rises very nearly to the ground level and the working lift was about 32 feet. The gauged discharge of the pump was 265 miners' inches or 5·30 cusecs. The pump was vertical and driven by a horizontal motor through a quarter twist belt. Most of the wells consist of a single tube 10 or 12 inches in diameter and sunk to a depth of from five to six hundred feet. Vertical motors mounted on the pump shaft are not employed as the pumps have to be lowered occasionally and whilst the wooden shaft is being sunk it is necessary to keep the pump running. It is, therefore, suspended by a stout wooden framing from beams fixed at the floor level of the motor shed. Formerly all the wells used to flow but now no water can be obtained except by pumping and the cost of irrigation per acre has been raised from Rs. 6 to Rs. 23

Mr. Pedley, the General Manager of the San Jacinta Land Company, thus briefly narrates the history of the Temescal Water Company's plant. "Ten years ago this company had flowing artesian wells, but the supply gradually decreased owing to a series of dry years, and then the company began to pump from some of the weaker wells in order to supplement the supply from the stronger ones and in a short time all the wells ceased to flow. The pumping was begun with centrifugal pumps and oil engines. The water level fell steadily about ten feet per year and the wells were then dug down to water level and the pumps lowered. This process was unsatisfactory and expensive in every way. The pumps were not suitable for the greater

depths and the engines were not powerful enough and so had to be changed. Then the company experimented with a steam driven air compressor and raised the water by injecting compressed air into the wells at a point about 160 feet below the surface; the bubbles of air, raising rapidly, expand as the pressure decreases and so lighten the column of water that the pressure at the bottom is sufficient to eject a considerable stream of mixed air and water. The process was convenient and reduced labour because the air was all compressed at a central station and piped to about 20 different wells doing away with a number of small oil engines. It was, nevertheless, very expensive, and, finally, the company had to adopt electric power generated at a main station and distributed to motors."

The brief account is interesting as typical of what is going in the country not only in regard to irrigation by pumping or even irrigation generally but in regard to almost all fields of activity. Some one lights upon a good thing and every one wants to be in it, over development ensues and difficulties are created, which are met by heroic methods, the very boldness of which contributes not a little to the ultimate success. The Californian orange grower has in some respects very favourable conditions under which to work. His present prosperous condition is due not only to making the most of them but also to the display of unusual skill and energy combined with adequate capital to command the services of the best obtainable expert engineering assistance and further to what is perhaps almost as important, unbounded faith in the possibilities of modern engineering.

The average American, if he reads nothing else, reads his Sunday papers and dwells with huge delight and complacency on the popular science sections, in which are recorded the triumphant applications of physical science to the solution of the material problems which constantly arise in the strenuous efforts they are making to open up the vast territories they have occupied.

Pumping by Compressed Air.—The Pohlè Air lift is largely used for raising water from tube wells and is especially convenient where the wells are of small capacity and fairly numerous. For dealing with large bodies of water its mechanical inefficiency is against it but in other respects it is extremely satisfactory and requires no supervision outside that necessary for driving the air compressing plant. Through the kindness of Mr. J. B. Lippincourt, the Supervising Engineer of the U. S. Geological Survey in Los Angeles, I was furnished with a copy of a report on the efficiency of these lifts made by Mr. David S. Macpherson. The experiments were made at the Cudahy ranch where 9 wells have been sunk at distances ranging from 20 to 800 feet from the air compressors. The wells are all 12in. tubes perforated in the water bearing starta. The statical level of the water is 45 feet below the surface but the pumping lowers it about 15 feet so that the total lift during the trials was 60 feet. The power plant consisted of 4 single cylinder air compressors each 16in. × 18in. Two of the cylinders were driven by direct acting steam engines and two by a single cross compound engine. The air compressors all deliver into a common receiver and the power required to drive one

of the compressors was found by indicating one of the direct acting engines and multiplying the result by four. The wells discharge into a common flume and by current meter observations the flow was determined to be 6·014 cusecs equal to 41·1 H. P. in the water lifted. Four times the indicated H. P. required to drive a single compressor was 173·34, so that the efficiency of the plant was 23·7 per cent. In each of the wells a 6in. tube was submerged 90 feet and the compressed air from the receiver at a pressure of 45 lbs. per square inch is carried in a small pipe down the well and the end of it is turned up so as to discharge the air into the 6in. delivery pipe.

The most recent practice favours a submersion of the delivery pipe from $2\frac{1}{2}$ to 3 times the height to which the water is to be lifted and the air pressure should be just sufficient to allow a free flow. The methods by which the above stated efficiency was determined are, of course, open to criticism as lacking in accuracy but they are probably devoid of serious error and agree with the generally prevalent impression among Californian engineers that the efficiency of well established plants is in the neighbourhood of 23 per cent.

Several installations were visited in the country round Pasadena in company with Mr. J. B. Lippincott to whom I am greatly indebted for much courteous assistance when making enquiries in this matter. Part of the water supply for the town is derived from 4 wells each of 10in. bore sunk to a depth of about 400 feet. The discharge pipes were 6in. in diameter and the lift about 60 feet. The air compressor was of the two stage type and the pressure in the receiver was 80 lbs. per square inch. The water was raised to

ground level and after passing through a settling tank to get rid of any sand was lifted an additional 40 feet by a centrifugal pump driven off the fly wheel shaft of the air compressor. The plant belonged to the West Side Water Company and as its purchase by the town was under consideration, the engineer in charge was unable to afford any information regarding efficiency or working expenses.

The second installation belonged to the East Whittier Land and Water Company and consisted of 14 wells discharging into a concrete flume. The lift was about 20 feet at the time but only a few wells were being drawn upon and when full supply is being taken it is probably considerably more. The air compressor was of the two stage type and was driven by a Corless engine, which under full load was capable of indicating 500 H. P. Steam was generated in tubular boilers, liquid fuel being used. One man was in charge of the station and there is no doubt that here, where labour is very expensive, the advantages of this method of lifting water were exemplified in a high degree.

At a third station near Delmonte there are 9 wells. Three with a lift of 70 feet and the other six with lifts of from 85 to 92 feet. A Smith Vaile compound engine indicating 140 H. P. drives the compressor which raises the air to a pressure of 56 lbs. per square inch, 6·2 c. ft. of free air are used per c. ft. of water lifted.

From enquiries subsequently made in London it appears that the Pohlè Air lift is very extensively used both in Great Britain and on the Continent. Mr. C. T. A. Hanssen, in an article contributed to the *Engineering Review* of July 1904, states that upwards of 900 installations are at work·

In a paper read before the British Association of Water Works Engineers, Mr. W. H. Maxwell, the Borough and Water Works Engineer of Tunbridge Wells, gave some interesting information regarding a Pohlè Air Lift which he had installed to supplement the water supply to the town. The boring is situated at a distance of 530 yards from the engine house, and is 350 feet deep; 200 feet is 15in. diameter and lined with solid steel tubing, 150 feet is 13½in. in diameter and lined with perforated tubing. The air compressing plant consists of two sets of two stage compressors with intercoolers. The steam cylinders are of 8in. and 12in. diameter and the air cylinders of 10in. and 6in. diameter, the stroke being 14in. The compressed air is carried to the well by a 4in. cast iron main terminating in a 2½in. pipe which descends to the bottom of the well and by a U. piece delivers the compressed air into the rising main which is 7in. in diameter. The cost of the installation excluding engine house, boilers, and lining and boring well was Rs. 50,625. A number of tests of the plant have been made which show clearly that the efficiency is greatly dependent on the ratio of the immersion of the air pipe to the height the water is lifted. In the trial, which gave the best result, the lift at the beginning was 84 feet and at the end 106·6 feet, and the ratio of immersion to lift varied from 3·01 to 2·2. The average discharge was 24,100 gallons per hour and the efficiency calculated on the I. H. P. of the engines was 36·8 per cent. and on the I. H. P. of the compressors 46 per cent.

Even better results were obtained with an Air Lift fitted up by Messrs. Hughes and Lancaster for raising sewage

at Rotherham. In a well 4 feet in diameter a rising main 12in. in diameter was fixed and immersed to a depth of 25 feet. Air under a pressure of 12 lbs. per sq. in. was delivered through a 3in. pipe. The lift was 9·50 feet. During a trial 1808·6 gallons per minute or 4·823 cubic feet per second were raised with 3·441 cubic feet of air per second. The efficiency was 49·5 per cent.

A well designed Air Lift is probably superior to a centrifugal pump as a machine for lifting water and it is the inefficiency of the methods of compressing air which are in the main responsible for the low ratio of the output of useful work to the total power expended in Air Lift plants. Messrs. Parsons and Co., of Newcastle upon Tyne, have introduced rotary air compressors of a construction somewhat similar to that of their well-known steam turbines and the results obtained with them are of a very promising character. Driven by steam turbines or electro motors such machines are likely to prove an immense advance on the cumbrous and costly air compressors of the reciprocating type with their very troublesome valves. The Air Lift is a device applicable with advantage only to deep tube wells and is not likely to be of much use in India,* where the wells are usually shallow and under normal conditions seldom contains any great depth of water. For the water supply of towns, and possibly also for irrigation, it might be worth while to experiment with tube wells, sunk by hydraulic jets in the deep sandy beds of some of our rivers. Air Lifts are the only

* Except in places where Artesian supplies of water have been found.

practicable means of drawing the water from such wells and it is more than probable that very large quantities of water could be obtained in this way. The wells would require protection from scour near the surface and the cheapest way would be to take advantage of some existing permanent masonry structure stretching across the river such as a bridge, anicut or causeway. American experience seems to show that the choking of the tubes by sand can easily be prevented.

Pumps.—American engineers have naturally paid a great deal of attention to machinery for lifting water and the Californian practice of to-day is the outcome of fully five-and twenty years' intelligent study of the many phases of the water lifting problem which irrigation necessities have brought into existence. For dealing with large quantities of water the centrifugal pump is universally employed and the details of its design have been gradually perfected so that it is now a fairly efficient machine capable of running continuously for long periods. Pump makers are prepared to guarantee efficiencies of from 60 to 75 per cent. the higher value with the larger pumps, but in practice, when the friction of the suction and delivery pipes is allowed for, the useful work in the water delivered is seldom more than 55 per cent. of the power expended. For high lifts two and three stage centrifugals are employed, the pumps being placed at the bottom of a pit sunk to the water level. They are invariably of the horizontal type with vertical shafts and are generally driven by quarter twist belts though in some instances where electricity is used the motors are fixed above ground on the top of the ver-

tical shafts. When the pumps are running, the downward thrust is partly or wholly balanced by the upward pressure on the pump wheel due to the suction entering on the top of the pump casing. When the pumps draw water from one or several tube wells grouped together foot valves are out of the question and at starting either steam ejectors or air pumps are used to create the necessary vacuum. Where foot valves are in use the pumps are primed from an overhead tank which is kept full of water and ready for use at any moment. For the rice irrigation in Texas and Louisiana both rotary and centrifugal pumps are used. The latter are preferred though the former are more efficient. The quantities of water dealt with are sometimes extremely large but the lift is not great, averaging about 20 feet. The diameters of the pump discharge pipes range up to as much as 60 inches with a delivery of 100 cubic feet per second. Direct coupled engines and pumps are not in favour and belt or rope drives are usually employed.

The enormous development of windmills for pumping water has led to a good deal of attention being paid to the design of small bucket pumps. A careful series of tests by Professor O. P. Hood published in the Water Supply and Irrigation Papers of the Geological Survey, show that efficiencies of over 80 per cent. are easily obtainable when the speed of working is not too great. The most important feature in the design of these pumps is the provision for the withdrawal of the piston and suction valve for examination or repair when the pump is submerged. On the oil fields of California I saw a large number of deep well pumps worked by wire ropes attached to a large eccentric driven

by an oil or steam engine. In some cases more than a dozen wells were being pumped by one centrally situated engine, which through a pair of bevil wheels drove a vertical shaft carrying an eccentric, to the sheaves of which the wire ropes radiating in all directions were attached. The shaft made about 15 revolutions per minute and the eccentric had a radius of 12in. giving the pumps a stroke of 2 feet. The wires were suspended in slings attached to cross arms on wooden poles and the pumps could be worked satisfactorily at a distance of half a mile from the engine. It seems to me that this system is capable of very extended application in this country where there are many tracts of country with numerous shallow wells, none of which are individually capable of yielding sufficient water to give employment to the smallest practicable installation of oil engine and centrifugal pump. By installing a bucket pump in each well and coupling it up by wire rope to a central station of this kind it will be possible to employ an oil engine to pump water from all the wells situated within a radius of half a mile. The efficiency of this method of transmitting power is fairly high and it ought to prove quite as economical a method of pumping as with centrifugal pumps. To adapt this system to irrigation a great many details have to be worked out but there appears to be nothing serious to overcome. It is certainly worth trying in this country because, if successful, it opens out a very wide field for the application of mechanical power to the lifting of water for irrigation.

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